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This research study was initiated to identify resistant materials for construction of wastewater treatment plants using the oxygen activated sludge process.

In this investigation, samples of a broad range of construction materials were exposed for periods up to 28 months in the aeration basins of three operating municipal wastewater treatment plants. All three plants were using oxygen-activated sludge processes during the exposure period. Materials exposed included metallics, portland cement concretes, protective coatings for steel and for concrete surfaces, sealers for joints in concrete, and plastic and rubber materials. An economic analysis was also conducted to evaluate the impact of materials recommendations generated by the exposure testing.

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MATERIALS FOR OXYGENATED WASTEWATER TREATMENT PLANT CONSTRUCTION

bу

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the projects of that research; a most vital communications link between the researcher and the user community.

The recent use of high purity oxygen in the activated sludge process represents an important advance in wastewater treatment. This report evaluates materials of construction for use in high purity oxygen treatment plants and thus improves the application of oxygen technology in wastewater treatment.

Francis T. Mayo
Director
Municipal Environmental Research Laboratory

ABSTRACT

This research study was initiated to identify resistant materials for construction of wastewater treatment plants using the oxygen activated sludge process.

In this investigation, samples of a broad range of construction materials were exposed for periods up to 28 months in the aeration basins of three operating municipal wastewater treatment plants. All three plants were using oxygen-activated sludge processes during the exposure period. Materials exposed included metallics, portland cement concretes, protective coatings for steel and for concrete surfaces, sealers for joints in concrete, and plastic and rubber materials. An economic analysis was also conducted to evaluate the impact of materials recommendations generated by the exposure testing.

This report was submitted in fulfillment of Contract No. EPA-IAG-0187(D) by the Bureau of Reclamation under the sponsorship of the U.S. Environmental Proection Agency.

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SECTION 1

INTRODUCTION

To cope with the ever-increasing quantities of wastewaters to be treated, considerable emphasis is now being placed on the use of new cost-effective advanced treatment processes. One such process is aeration with high purity oxygen in lieu of the traditionally used atmospheric air. The use of oxygen for aeration offers more efficient and complete oxygen absorption than obtainable using air. Greater efficiency and the consequent reduction in retention time will result in allowing existing facilities to increase their capacities or throughput rates without increasing physical plant size. This advantage notwithstanding, it was recognized that the use of the oxygen activiated sludge process may result in accelerated deterioration of materials normally used for construction of conventional wastewater treatment plants.

Thus, in an Environmental Protection Agency-sponsored study, the Bureau of Reclamation was charged with identifying resistant materials of construction suitable for use in plants using this advanced process. In this investigation, samples of a broad range of construction materials were exposed. Exposure periods were up to 28 months in the aeration basins of three operating municipal wastewater treatment plants. All were using oxygenated activated sludge processes. Materials exposed included metallics, portland cement concretes, protective coatings for steel and for concrete surfaces, sealers for joints in concrete, and plastic and rubber materials. The three (site 1); the Speedway Wastewater Reclamation Facility, Calabasas, California (site 2); and the Westgate Wastewater Treatment Plant, Indianapolis, Indiana (site 3). Each plant uses a different oxygen process and all three plants treat mostly domestic sewage.

An economic analysis was conducted to evaluate the impact of materials recommendations generated by the exposure testing on construction costs.

SECTION 2

CONCLUSIONS

Many variables require consideration in arriving at sound materials selection. These factors include mechanical requirements, reliability, maintenance considerations, wastewater chemistry, materials availability and ease of specification, and safety considerations. Because the multidisciplinary nature of these facets is not within or is only marginally within the scope of the authors' expertise, no effort has been made to recommend materials of construction for every component in oxygenated wastewater treatment plants. Rather, below is a list of materials which were shown to be resistant to this environment as indicated by this study. As applicable, the materials are listed in order of resistance (highest resistance first) or, in the case where more than one material displayed identical resistance, in alphabetical order.

1. Concretes. -

- a. High-quality conventional concretes made with either Type II or Type V portland cement are suitable for oxygenated wastewater, secondary treatment tank construction. The selection of type of cement used should be based on the sulfate concentration of the particular wastewater. In plants where primary treatment does not remove all debris, either additional sacrificial thicknesses of concrete or a protective coating may be needed.
- b. Significant reductions in strength occurred in the polymer-impregnated concrete. Nevertheless, strengths remained higher than for nonimpregnated concretes. Therefore, further long-term tests would be required to assess the performance of this material.
- 2. Steel embedded in concrete. A 41-mm (1.6-inch) thick cover of dense, high-quality concrete provides excellent corrosion protection for embedded steel.

3. Alloys. -

- a. The following alloys may be used unprotected in these environments. However, normal sound corrosion engineering principles should be followed, e.g., adverse bimetallic couples should not be exposed.
 - (1) Stainless steel, Type 201

- (2) Stainless steel, Type 304
- (3) Stainless steel, Type 316
- (4) Sensitized stainless steel, Type 304
- (5) Sensitized stainless steel, Type 316
- (6) Deoxidized copper
- (7) Austenitic cast iron
- b. The following alloys should not be exposed unprotected in these environments. It should be recognized that addition of sacrificial thicknesses of gray cast iron is a form of corrosion protection widely practiced in the industry.
 - Aluminum alloy 6061 (1)
 - (2) Gray cast iron
 - (3) Low alloy steel
 - (4) Mild steel

4. Plastics and rubbers. -

- a. The lack of substantial difference in physical properties of polymers tested between tap water and wastewater exposures as well as between gas and liquor exposures, and the relative stability of polymers known to be sensitive to oxidation, indicates that the exposures encountered in this study do not represent a severe oxidation environment for higher polymers.
- b. Selection of any of the tested products for use in wastewater treatment plants using oxygen for aeration should be made on the basis of established engineering properties dictated by the specific intended use. Products should be especially formulated for resistance to bacterial attack.

5. Protective coatings. -

a. For steel surfaces

Phenolic-epoxy, proprietary, coating No. C-12

Urethane, proprietary, coating No. C-9

- Coal-tar epoxy, MIL-P-23236, Type I, Class 2, coating No. C-4 (4)
- Phenolic, proprietary, coating No. C-8
- Vinyl resin, USBR VR-6, coating No. C-2
- Phenolic-epoxy, proprietary, coating No. C-16 Urethane, proprietary, coating No. C-13 (7)
- (8) Vinyl resin, USBR VR-3, coating No. C-1

b. For concrete surfaces

- (1) Phenolic-epoxy, proprietary, coating No. C-12
- Urethane, proprietary, coating No. C-9
- Coal-tar epoxy, MIL-P-23236, Type I, Class 2, coating No. C-4

- (4) Phenolic-epoxy, proprietary, coating No. C-16(5) Urethane, proprietary, coating No. C-7
- 6. Sealers for concrete joints.
 - a. Silicone, one-component, low modulus, sealer No. S-4
 - Polysulfide, two-component, Federal Specification TT-S-00227, sealer No. S-3
- 7. Added costs of the more durable materials, indicated for use by the results of this study, are negligible when compared to total construction costs.

SECTION 3

EXPOSURE CONDITIONS

Tapia Site

Samples were placed in the secondary treatment facility at the Tapia site which is a 9.1- by 36.0- by 4.6-m (30- by 118- by 15-foot) water depth spiral-flow aeration tank (figures 1, 2, and 3).

Nominal flow is 44.8 ℓ /s (1.0 Mgal/d) primary effluent plus 30 percent return activated sludge. High-purity oxygen is diffused into the mixed liquor from special submerged aeration diffusers along one side of the length of the tank.

Oxygen not dissolved or utilized in the mixed liquor is captured by an inflated polyvinyl chloride tent which covers and seals the tank. This oxygen, together with other gases, mainly carbon dioxide, a product of organic metabolism, is then recycled into the mixed liquor by an 850 ℓ /s (1.8 x 10 the opposite side of the tank to provide the principal aeration and the spiral-flow agitation of the mixed liquor.

Speedway and Westgate Sites

Samples were placed in secondary treatment oxygen contact tanks (figures 4, 5, and 6). In both these plants, high-purity oxygen is fed into the gaseous zone between the liquid surface and the tank cover under moderate pressure [approximately 17-kPa (2.5 lb/in²)g]. A mechanical agitator with impellers at the liquid surface and at approximately one-half the liquid depth, diffuses the high-concentration oxygen atmosphere into the mixed liquor. (The impeller at the liquid surface resulted in splashing on the test specimens exposed in the gaseous phase.)

Typical characteristics of these systems during the sample exposure period are shown in table 1. (Essentially duplicate tables, as applicable, are provided to reflect both SI and English units.)

The Westgate site differs from the other two sites in that its primary treatment consists of only a bar screen for removal of large debris. The other two sites have complete primary treatment facilities.

Specimen Location

Test specimens were exposed in three zones (gaseous, interface, and liquor) of the covered aeration basins at each of three test sites.

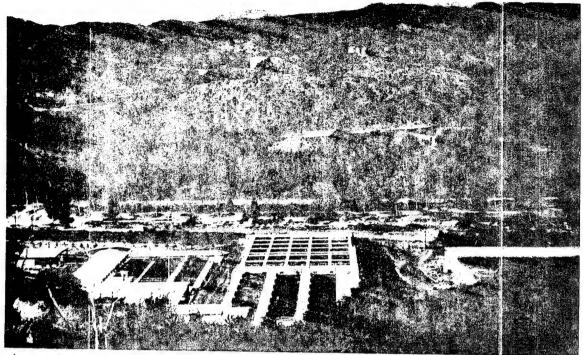


Figure 1. Overall view of the Tapia Water Reclamation Facility (site 1), Calabasas, California. Polyvinyl chloride tent covering the secondary tank in which exposures were made is shown in the left foreground.

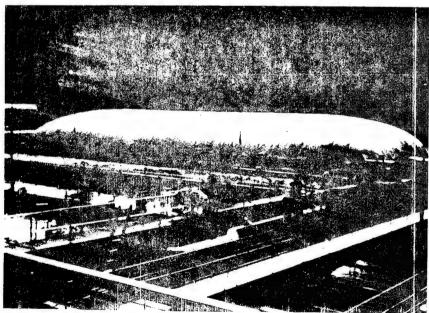


Figure 2. Closer view of the polyvinyl chloride tent at site 1.

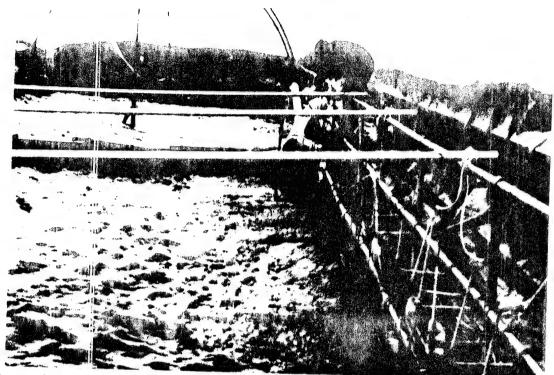


Figure 3. View inside the tent at site 1. Concrete cylinders exposed in the gas phase can be seen (right foreground) along the downstream end of the tank.

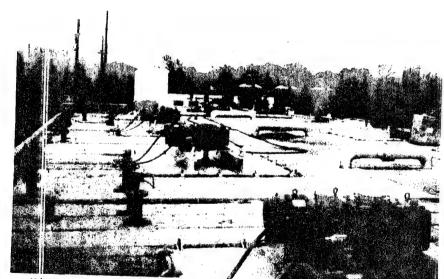


Figure 4. View of one of the secondary treatment trains at the Speedway plant (site 2). Covers for tanks are constructed of concrete.

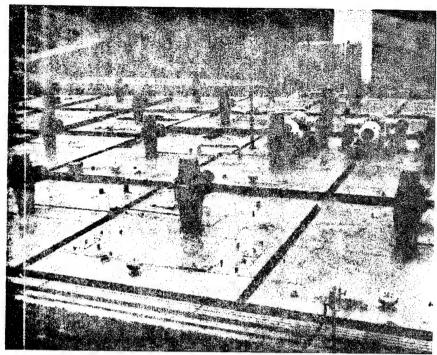


Figure 5. View of Westgate plant (site 3). Motors drive impellers located at the liquor surface and in the liquor. This plant utilizes steel covers.

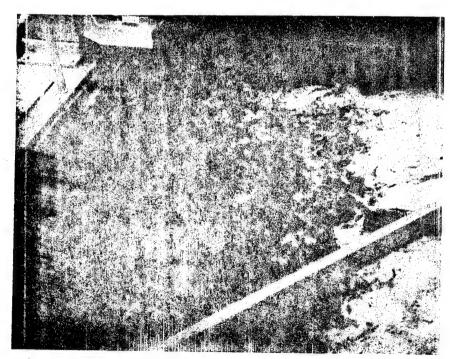


Figure 6. View of site 3 term with cover removed to show splashing caused by the surface impeller. Test specimens were exposed to this splash zone effect.

TABLE 1. - TYPICAL MIXED LIQUOR SUSPENDED SOLIDS WASTEWATER ANALYSES

		Site	
Property	No. 1	No. 2	No. 3
Conductivity (mho/cm)	0621	2087	17.69
Hď	7-7	7 0 7	~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
Total suspended solids (mg/ℓ)	3700	2275	6044
Organic material, filterable (mg/k)	1	516	328
S1 0 (mg/g)	11.0	36,5	36
Total dissolved solids (mg/E)	840	816	1428
Cations and anions (mg/k)			
Calcium	6 17	Ċ	ò
Magnetin	7.11	00	0.40
riagnes i un	35.1	33.7	40°
Sodium	133.0	150.0	48.3
Potassium	26.6	34.4	109.5
Carbonate	0.0	0.0	0.0
Bicarbonate	659.0	10.98	472.0
Sulfate	26 . 4	0.2	1.9
Chloride	144.0	7.4	78.1
Nitrate	96.4		;) 1

* Site No. 1 - Tapia Water Reclamation Facility, Calabasas, California Site No. 2 - Speedway Wastewater Treatment Plant, Indianapolis, Indiana Site No. 3 - Westgate Wastewater Treatment Plant, Alexandria, Virginia

Racks for exposing the specimens at site 1 were fabricated of carbon steel; the racks were then hot-dip galvanized (figure 7). Racks used in sites 2 and 3 were constructed of stainless (Type 304) steel (figure 8).

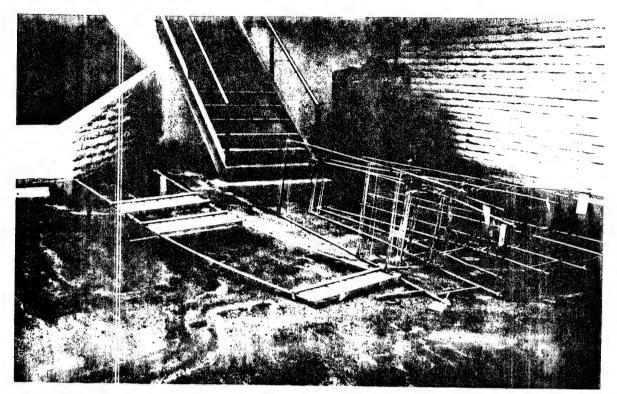


Figure 7. Typical rack used to expose test specimens at the Tapia plant.

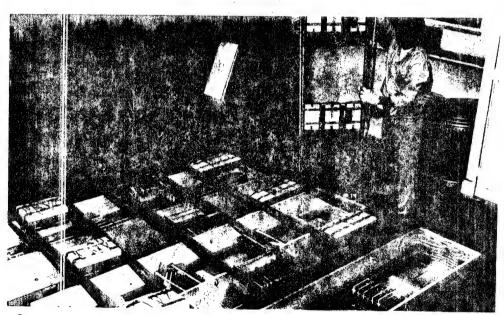


Figure 8. Racks for supporting test specimens at the Speedway plant. Similar but shorter racks were used at the Westgate plant.

SECTION 4

SPECIMEN INSTALLATION AND EXAMINATION

No modifications were necessary to enable the installation of the test specimens at site 1. Plant modifications were necessary at both sites 2 and 3 before the test specimens could be installed. The modifications consisted of removing existing covers from a portion of one of the reactor tanks and substituting a steel plate to support the specimen racks.

Initially, examinations were scheduled for 3-, 9-, and 18-month exposure periods. The actual examinations were performed in accordance with the

Examination	Exposure Site 1	time, months Sites 2 and 3
No. 1 No. 2 No. 3 Final	3 10 -	3 10 20
	22	28

SECTION 5

EVALUATION PROCEDURES

Concrete

Three types of portland cement concrete were exposed: (1) Type II cement, (2) Type V cement, and (3) polymer-impregnated concrete (PIC) consisting of Type II cement concrete which was impregnated with the monomer, methyl methacrylate, and polymerized. Mix designs for the concretes are contained in the Appendix (Section 9).

Concretes were evaluated by (1) determination of compressive strength change, (2) determination of length change, and (3) visual examination for change in surface condition. Length determinations and visual examinations were conducted at the exposure locations. Compressive strength specimens were shipped to the Denver Laboratories for testing.

Compressive strength specimens were standard 76- by 150-mm (3.0- by 6.0-inch) cylinders. The length change cylinders (also 76- by 150-mm) were fitted with standard metal inserts for length measurements.

Steel Embedded in Concrete

Samples of concrete containing short sections of reinforcing steel were exposed to determine the effect of the test environments on the corrosion rate of the embedded steel. The reinforcing steel sections, 100 mm (4.0 inches) long by 19 mm (0.75 inch) diameter, were cast in 100- by 100- by 200-mm (4.0- by 4.0- by 8.0-inch) long concrete (Type II, Type V, and PIC) prisms, providing a concrete cover of 41 mm (1.6 inches) minimum over the steel. Copper lead wires were attached to the reinforcing steel prior to concrete placement to provide access for electrical tests.

Measurement of corrosion was accomplished by two nondestructive methods, including steel-to-electrolyte potential measurement and corrosion current determination.

Steel-to-electrolyte potential was referenced to copper-copper sulfate electrode (CSE). Magnitude of corrosion current was then determined only on those specimens showing a high negative (more negative than minus 0.30 volt) steel-to-electrolyte potential. The potential of uncorroded steel in concrete is in the range of minus 0.10 to minus 0.30 volt to CSE. When corrosion develops, the potential drops to that of corroding steel which is about minus 0.55 volt to CSE. Determination of corrosion current was by the polarization break method, devised by Swerdtfegar of the National Bureau of Standards, described in the Appendix.

The results of the nondestructive tests conducted at the exposure sites were compared to actual corrosion of the embedded steel as determined after removal of the concrete cover at the conclusion of the test.

Alloys

1. Unstressed specimens. - Circular coupons [56.7 mm (2.23 inches) in diameter] were exposed on standard corrosion test spools. All wrought alloy specimens were 1.6 mm (0.063 inch) thick and the coupons of cast alloys were 3.2 mm (0.13 inch) thick. Metals and alloys tested are identified in table 2 and mill test data appear in table 3. Test spools were fabricated of Type 316 stainless steel and individual coupons were insulated from the spool and from each other through use of teflon rod insulators and teflon spacers. Duplicate specimens of each alloy were exposed. Spacing between coupons was 13 mm (0.50 inch). The spacers also provided a crevice whereby concentration effects could be evaluated.

Sufficient replicate specimens were exposed such that duplicate specimens could be shipped to the Denver Laboratories for evaluation. Average corrosion rate was computed from weight loss data, and localized corrosion was determined through pit depth measurements. Procedures for preparation of coupons for exposure and cleaning of specimens after exposure are described in the Appendix.

2. Stressed specimens. - In addition to the unstressed circular coupons, stressed specimens of the wrought metals and alloys were also prepared. The stress specimens [200 by 13 by 1.6 mm (8.0 by 0.50 by 0.063 inch)] were bent over a 25-mm (1.0-inch) mandrel and retained in this position to provide plastic deformation as well as high tensile stresses.

Stressed specimens were evaluated by visual examination for cracking.

Rubber and Plastics

Materials selected for exposure are listed in table 4.

Twelve rubber materials were selected for exposure. Duplicate sets of dumbbell-shaped, tensile specimens were cut from each material in accordance with ASTM: D 412. Holes for mounting specimens on the racks were punched 13 mm (0.50 inch) from each end of the specimens. The specimens were then looped (end to end) and retained in this position to provide both stressed and unstressed areas during exposure.

The three flexible plastic sheeting materials were cut into duplicate 25-mm (1.0-inch) wide, parallel edge, tensile test strips in accordance with ASTM: D 882. These specimens were not looped since stress relaxation characteristics of the flexible plastic do not make this appropriate.

TABLE 2. - IDENTIFICATION - ALLOYS

A-1 12 Gray cast iron ASTM: A 48 A-2 7 Mild steel AISI 1020 A-3 7-CT Low alloy steel ASTM: A 606 A-4 21-201 Stainless steel AISI 201 A-5 18-304 Stainless steel AISI 304 A-6 18-304S Stainless steel AISI 316 A-7 19-316 Stainless steel AISI 316 A-8 19-316S Stainless steel AISI 316 A-8 19-316S Stainless steel AISI 316 A-9 13-1 Nickel cast iron ASTM: A 436 A-10 41-103 Deoxidized copper ASTM: B 152 A-11 43-6061 Aluminum AA-6061	Code No.	coupon	Alloy type	Specifications*
7 Mild steel AISI 1 7-CT Low alloy steel ASTM: 21-201 Stainless steel AISI 3 18-304 Stainless steel AISI 3 18-304S Stainless steel AISI 3 19-316 Stainless steel AISI 3 19-316S Stainless steel AISI 3 19-316 Stainless steel AISI 3 19-103 Deoxidized copper ASTM: 41-103 Deoxidized copper ASTM: 43-6061 Aluminum AA-606	A-1	12	Gray cast iron	1
7-CT Low alloy steel ASTM: 21-201 Stainless steel AISI 3 18-304 Stainless steel AISI 3 18-304S Stainless steel AISI 3 19-316 Stainless steel AISI 3 19-316S Stainless steel AISI 3 19-316S Stainless steel AISI 3 13-1 Nickel cast iron ASTM: 41-103 Deoxidized copper ASTM: 43-6061 Aluminum AA-606	A- 2	1	Mild steel	AISI 1020
21-201 Stainless steel 18-304 Stainless steel 18-304S Stainless steel 19-316 Stainless steel 19-316S Stainless steel 19-316S Stainless steel 13-1 Nickel cast iron 41-103 Deoxidized copper 43-6061 Aluminum	A-3	7-CT	Low alloy steel	ASTM: A 606
18-304 Stainless steel 18-304S Stainless steel, sensitized 19-316 Stainless steel 19-316S Stainless steel, sensitized 13-1 Nickel cast iron 41-103 Deoxidized copper 43-6061 Aluminum	A-4	21-201	Stainless steel	AISI 201
18-304S Stainless steel, sensitized 19-316 Stainless steel 19-316S Stainless steel 13-1 Nickel cast iron 41-103 Deoxidized copper 43-6061 Aluminum	A-5	18-304	Stainless steel	AISI 304
19-316 Stainless steel 19-316S Stainless steel, sensitized 13-1 Nickel cast iron 41-103 Deoxidized copper 43-6061 Aluminum	A-6	18-3048		AISI 304
19-316S Stainless steel, sensitized 13-1 Nickel cast iron 41-103 Deoxidized copper 43-6061 Aluminum	A-7	19-316	Stainless steel	AISI 316
13-1 Nickel cast iron 41-103 Deoxidized copper 43-6061 Aluminum	A-8	19-3168	Stainless steel, sensitized	AISI 316
41-103 Deoxidized copper 43-6061 Aluminum	4-9	13-1	Nickel cast iron	ASTM: A 436
43-6061 Aluminum	A-10	41-103	Deoxidized copper	ASTM: B 152
	A-11	43-6061	Aluminum	AA- 6061

* ASTM - American Society for Testing and Materials AISI - American Iron and Steel Institute AA - Aluminum Association

TABLE 3a. MILL TEST DATA - ALLOYS (metric units)

Carbon (percent by weight) Carbon (Mangeness	316 stainless 316 st steel stee Egersell Inge A1019 A1	16 stainless H-Resist, steel 1/ Type I Ingersoll Brass 41019 13620	Mental Section 1	130-54 110-4 110-
0.10				
0.10			•	•
0.10		1.55	•	•
0.019 0.009 0.009 0.009 0.009 0.009 0.009 0.009 0.009 0.100 0.11 0.11			•	•
0.10 0.70 0.70 0.70 0.70 0.70 0.70 0.70			•	•
0.11 3.5-5.5 9.10 9.10 18.50 1			•	•
1.06 M.0-18.0 18.3			•	•
0.30			•	•
0.30			•	•
## 495.6 795.0 642.3 642.3 145.2 145			2.2	•
## 493.6 793.0 642.3 543.2 543			•	•
6 493.6 793.0 642.3 642.3 143.2 143.		•	•	•
## 495.6 795.0 642.3 642.3 545.2 545		•	.0	•
## 493.6 793.0 642.3 642.3 543.2 545		. 10	•	•
## 493.4 793.0 642.3 642.3		•	•	•
Pa - 493.6 793.0 642.3 642.3 Pa - 361.2 276.6 343.2 343.2				
We - 381.2 276.6 343.2 345.2			228.4	•
	266.1 266.1		3	•
Percent in 30 ms 31	•	•		•

TABLE 3b. MILL TEST DATA - ALLOYS (English units)

Alloy code No. Coupon (dout)fication Metalia No.	A-1	A-2	A-3 7-CT	A-4 21-201 75	A-5 18-304 656		A-7 19-316 657	A-8 19-316S 657	1-61 13-1	A-10 41-103	A-11 43-606
Alloy name MIII	Gray cast iron	Hild	Low alloy sreel U.S. Strel	201 stainless steel Jorgenson	304 stainless steel Fortuna	30% stainless steel 1/ Fortuna	316 stainless steel Ingersoil	316 stainless sterl 1/ Ingersoil	Ni-Resist, Type I Standard	Deaxidized copper Standard	Alumin
Heat No.	ı	ı	041534	٠.	360792	360792	61019	61019	13620	*****	•
Chemical analysis (7 by wright)					,						
Carbon	,	•	0.10	≥0.15	0.05	0.05	0.07	0.01	2.70		'
Hanganeec	,	•	0.42	5.5-5.75	1.45	1.45	1.55	1.55	1.25		•
Phorphorus	,	1	0.10	,	0.026	0.026	0.018	0.018		•	•
Sulfur		,	0.019		0.009	0.000	0.003	0.003			•
Silicm			0.35	> 1.00	0.70	0.70	0.64	75.0	2.15		•
Nickel		•	0.11	3.5-5.5	9.10	9.10	13.15	13.15	15.75	•	•
Chromitum			1.06	16.0-18,0	18.50	18.50	16.03	16.03	2.03	ı	•
Hol ybelcum	,	,	,				2.40	2.40	1	,	•
Copper			0.30		,		0.13	0.13	92.9	49.98	•
Columbium	,	,	•		.*		•				٠
Titanium		,				•	•		,		•
Roron	,	,		•	•		,	1	•	0.02	•
Cobalt		4		•	•	•	0.10	0.10	•	•	•
Aluminum		1	i,	ŧ	i	,	•				•
Physical propettins											
Tensile etrength (16/4n ²)			71,445	115,000	93,163	93,163	85,400	38,900		33,000	' '
Cloueatton (2 in 2 in.)			10	20010:	****				,		٠

1/ Sensitized

Rubber Sheeting

- R-5 Neoprene Gaco Western, Inc.
- R-8 EPDM Carliele Tire and Rubber Company
- R-17 Butyl Carliale Tire and Rubber Company
- R-18 CSPE Gaco Western, Inc.
- R-25 Natural Goodyear Tire and Rubber Company
- R-27 Polyacrylate Thiokol Chemical Corporation
- R-29 Butyl Gates Rubber Company
- R-30 EPDM Gates Rubber Company
- R-31 Butyl-EPDM blend Presetite Division, Interchemical Corporation
- R-32 Silicone Dow Corning Corporation
- R-34 Mitrile Butadiene B. F. Goodrich Chemical Company
- R-532 Silicone General Electric Company

Plastic Sheeting

- B-6273 CSPE Reeves Brothers, Inc.
- B-6475 CPE Goodyear Tire and Rubber Company
- B-6514 PVC Pantasote Plastics Company

Fabric Reinforced Flexible Sheeting

- E-6386 Nylon reinforced CSPE Burke Rubber Company
- B-6399 Nylon reinforced EPDM Firestone Coated Fabrics Company
- B-6464 Nylon reinforced Butyl Plymouth Rubber Company, Inc.
- B-6467 Nylon reinforced CPE Snyder Manufacturing Company
- B-6468 Nylon reinforced CPE Snyder Manufacturing Company

Rigid Polymers

- RS-1 Epoxy-fiberglass Shell Chemical Company
- RS-2 Polyester-fiberglass Atlas Chemical Industries, Inc.
- RS-3 Vinyl-fiberglass Dow Chemical Company
- RS-4 RPM pipe Johns-Manville Corporation
- RS-5 HDPE Mancor, Inc.
- EPDM Ethylene Propylene Diene Monomer
- CSPE Chlorosulfonated Polyathylene
- CPE Chlorinated Polyethylene
- PVC Polyvinyl Chloride
- RPM Reinforced Plastic Mortar
- HDPE High Density Polyethylese

The five, fabric-reinforced, flexible synthetic materials were cut into 76- by 100-mm (3.0- by 4.0-inch) specimens for hydrostatic pressure testing according to ASIM: D 751, diaphragm burst method.

These specimens were also exposed in a looped condition to provide both stressed and unstressed areas.

Four rigid, fiberglass-reinforced polymers were cut into 51- by 150-mm (2.0- by 6.0-inch) samples for exposure. Edges of the exposed specimens were sealed with epoxy cement to reduce possible wicking in the reinforcement. Upon removal from exposure, these were bisected and trimmed to produce 13- by 150-mm (0.50- by 6.0-inch) specimens for flexure testing in accordance with ASTM: D 790, Method I.

High-density, polyethylene drain tubing samples were cut into 100-mm (4.0-inch) long specimens for visual examination.

The rubber and plastic materials were visually inspected at the time of removal from the exposure environment and then shipped to the laboratory for testing. In the laboratory the specimens were photographed and washed. Vapor specimens were hand dried and placed in an atmosphere of 50 percent relative humidity and 23°C for a minimum of 3 hours before testing. Interface and liquor specimens were immersed in fresh water after washing and maintained wet until 2 minutes (maximum) before testing.

Protective Coatings

Initially, nine coating systems were selected for exposure. However, six additional materials were introduced during the course of the test. Some of these, as appropriate, were applied to both metal (mild steel) and concrete (cement mortar) substrates. Metal panels were 150 by 150 by 3.0 nm (6.0 by 6.0 by 0.13 inch) and the concrete panels were 150 by 150 by 25 mm (6.0 by 6.0 by 1.0 inch). The systems applied are shown in table 5.

Surface preparation of the steel panels was by sandblasting to white metal; whereas, the concrete specimens were lightly sandblasted and sack-rubbed with a portland cement-sand grout prior to coating.

Specific application data are contained in table 6.

The coating was scored in an X pattern on one 150- by 150-mm (6.0- by 6.0-inch) surface of each panel to determine effects of discontinuities. In addition to the 15 coating systems exposed on panels, the racks used to expose the test specimens at site 1 were hot dip galvanized to provide a test of this coating material.

Evaluation was accomplished by periodic visual observation at the test site, and visual examination in the Denver Laboratories at the end of the exposure.

TABLE 5. IDENTIFICATION - PROTECTIVE COATINGS SYSTEMS

Code No.	Generic type	Materials specifications	Manufacturer	Manufacturers designation	Tes	Tested on
						מווכז פרפ
C-3	Vinyl resin	USBR VR-3	Ameron	400000	;	
C-2	Vinyl resin	USBR VR-6	Ameron	Amercoat 33	×÷	×
C-3	Coal-tar enamel	AWWA C-203	Konners Co	Bitument 23	≺ :	,
0-4	Coal-tar epoxy	Mil-P-23236,	Porter Coatings	Tarest Ctandard	× ;	×:
		Type I,	0	זמומבר ארמווחמות	∢	*
		Class 2				
C5	Butyl	1				
0 - 6	Butwl	ı	U.S. Polymeric	PC-8152	×	×
) r	11	•	Enjay	6120	×	×
200	Urethane	ı	Carboline	X 1304-146	ł	: >
ه دا	Phenolic		Carboline	Phenoline 368WC	>	4
C-3	Urethane	1	Crandalon	Crandalon	: >	>
	Anodizing	ı	CHN Anodizing	Anodized	: ×	4
-11-0	2017	ASTM: A 123	Boyles Galvan-	Hot-dip gal-	· ×	
0-10*	Dhono 1 i o		izing	vanize		
1	tuenotto epoxò	ı	Wisconsin Pro-	Plasite 7122	×	×
7-13*	Tropia de la companya		tective Coatings			!
0 - 1 C	or e chane	ì	Grove Specialties	Monopol GS-300	×	×
. サT・	Urethane	ı	United Paint	Ilni-Tile	; >	€ >
C-15%	Urethane	1	Gaco Western	THE TOTAL	۲	∢ ;
C-16*	Phenolic epoxy	1	Wisconsin Pro-	Plasite 7155 HHR	>	× >
			tective Coatings	Tim Cott on the	<	<

* Exposed at sites 1 and 2 only.
** Exposed at site 1 only.

TABLE 6a. APPLICATION DATA - PROTECTIVE COATING SYSTEMS (metric units)

Code No.	Substrate	Application data	Application method	Total dry film thickness (mm)
C-1	Steel Concrete	Four coats First coat thinned 1:1 with vinyl thinner + three coats	Brush Brush	0.15 0.15
C-2	Steel	Primer + three body coats + two seal coats	Brush	0.25
C~3	Steel Concrete	Primer + one coat Primer + one coat	Dip Dip	2.54 2.54
C-4	Steel Concrete	Three coats First coat thinned 1:1	Brush Brush	0.50 0.50
C-5	Steel Concrete	Primer + two topcoats Primer + two topcoats	Brush Brush	0.38 0.38
C-6	Steel Concrete	Two coats Two coats	Brush Brush	0.45 0.45
C-7	Concrete	Primer + topcoat; topcoat thinned one pint/gallon of paint with 1:1 xylol/MEK mixture	Brush	0.50
C-8	Stee'	Primer (thinned 1 pint/gallon with 2:1 xylol/MEK mixture) + two topcoat	Brush s	0.50
C-9	Steel	Airless spray application by manu-	Spray	0.76
	Concrete	facturer Airless spray application by manu- facturer	Spray	0.76
C-10	Steel	Electrochemical application to gal- vanized panels by manufacturer	-	
C-11	Steel	Hot-dip galvanized	Hot dip	0.07
C-12	Steel Concrete	Five coats First coat (thinned 1:1 with manufacturer's thinner) + four coats	Brush Brush	0.38 0.38
C-13	Steel Concrete	Three coats Three coats	Brush Brush	0.88 0.88
C-14	Steel Concrete	Primer + one topcoat Primer + one topcoat	Brush Brush	0.38 0.38
C-15	Concrete	One coat	Brush	0.38-0.50
C-16	Steel Concrete	Three coats First coat (thinned 1:1 with manu- facturer's thinner + two topcoats	Brush Brush	0.30 0.30

TABLE 6b. APPLICATION DATA - PROTECTIVE COATING SYSTEMS (English units)

Code No.	Substrate	Application data	Application method	Total dry film thickness, (mils)
C-1	Steel Concrete	Four coats First coat thinned 1:1 with vinyl thinner + three coats	Brush Brush	6 6
C-2	Stee!	Primer + three body coats + seal coat	Brush	10
C-3	Steel Concrete	Primer + one coat Primer + one coat	Dip Dip	100 100
C-4	Steel Concrete	Three coats First coat thinned 1:1 with xylene	Brush Brush	20 20
C-5	Steel Concrete	Primer + two topcoats Primer + two topcoats	Brush Brush	15 15
C-6	Steel Concrete	Two coats Two coats	Brush Brush	18 18
C-7	Concrete	Primer + topcoat; topcoat thinned 1 pint/gallon of paint with 1:1 xylol/MEK mixture	Brush	20
8-3	Steel	Primer (thinned 1 pint/gallon with 2:1 xylol/MEK mixture) + two topccat	Brush s	20
C-9	Steel	Airless spray application by manufacturer	Spray	30
	Concrete	Airless spray application by manufacturer	Spray	30
C-10	Steel	Electrochemical application to gal- vanized panels by manufacturer	-	-
C-11	Steel	Hot-dip galvanized	Hot dip	3
C-12	Steel Concrete	First coat (thinned 1:1 with manufacturer's thinner) + four coats	Brush Brush	15 15
C-13	Steel Concrete	Three coats Three coats	Brush Brush	35 35
C-14	Steel Concrete	Primer + one topcoat Primer + one topcoat	Brush Brush	15 15
C-15	Concrete	One coat	Brush	15-20
C-16		Three coats First coat (thinned 1:1 with manufacturer's thinner) + two topcoats	Brush Brush	12 12

Joint Sealers

Initially three synthetic rubber, joint sealing materials were exposed, a polysulfide, a polyurethane, and a silicone, all two-component sealers conforming to the physical test requirements of Federal Specification TT-S-227. During the course of the tests, two additional materials were exposed, a coal-tar extended polysulfide material conforming to USBR specifications and normally used for sealing contraction joints in concrete canal lining, and a single-component, low modulus silicone sealant. The sealers exposed are listed in table 7. These materials were cast in a 150- by 13- by 13-mm (6.0-by 0.50- by 0.50-inch) joint formed by two concrete (cement mortar) slabs.

Two specimens of each sealer were prepared for exposure in each zone. After curing, one specimen was extended 25 percent to a joint width of 16 mm (0.63 inch) and the other compressed 25 percent to 9.5-mm (0.38-inch) joint width.

Evaluation was accomplished by visual observation for adhesive or cohesive failure as well as for surface degradation.

TABLE 7. IDENTIFICATION - JOINT SEALERS

S-1 Silicone General Electric Company GE-1600 S-2 Urethane PRC Corporation PRC No. 4 primer 2 TT-S-22 S-3 Polysulfide W. R. Grace Company 2C primer Hornflex L sealant 2 TT-S-22 S-4 Silicone General Electric Company GE-Silpruf 1 - S-22 S-5 Coal-tar American Polytherm TRF-409 primer 1 USBR C3 Poly-Seal E-4 2 UsbR C3 Coal-tar American Polytherm TRF-409 primer 2 USBR C3 Coal-tar American Polytherm TRF-409 primer 2 USBR C3 Coal-tar American Polytherm TRF-409 primer 2 Cana.	Code No.	Generic type	Manufacturer	Manufacturer's designation	No. of Components	Specifications
Urethane PRC Corporation PRC No. 4 primer 2 TT PRC 270 sealant 2 Polysulfide W. R. Grace Company 2C primer Hornflex L sealant 2 TT Silicone General Electric Company GE-Silpruf 1 Coal-tar American Polytherm TRF-409 primer 1 polysulfide Company PRC 270 sealant 2 TT US HORDER Company POLY-Seal E-4 US	S-1	Silicone	General Electric Company	GE-1600	2	TT-S-227
Polysulfide W. R. Grace Company 2C primer Hornflex L sealant 2 TT Silicone General Electric Company GE-Silpruf 1 Coal-tar American Polytherm TRF-409 primer 1 polysulfide Company Poly-Seal E-4 2 US	S-2	Urethane	PRC Corporation	PRC No. 4 primer PRC 270 sealant	7	TT-S-227
Silicone General Electric Company GE-Silpruf 1 Coal-tar American Polytherm TRF-409 primer 1 polysulfide Company Poly-Seal E-4 2 US	S+3	Polysulfide	W. R. Grace Company	2C primer Hornflex L sealant	7 7	TT-S-227
Coal-tar American Polytherm TRF-409 primer 1 polysulfide Company Poly-Seal E-4 2 US	S-4	Silicone	General Electric Company	GE-Silpruf	1	ı
	S-5	Coal-tar polysulfide	American Polytherm Company	TRF-409 primer Poly-Seal E-4	1 2	USBR Class S canal sealer

SECTION 6

TEST RESULTS

Concrete

- 1. Compressive strength. Compressive strength test results are shown in tables 8, 9, and 10.
 - a. Conventional concretes made using Types II and V cement show no loss of strength at any exposure site.
 - b. PIC specimens showed large variations in strength under most exposure conditions. For sites 2 and 3, all exposures resulted in loss of strength.
- 2. Length change. Length change results are shown in tables 11, 12, and 13. Table 14 and figures 9, 10, and 11 show the effect of immersion in tap water on weight increase of the control specimens.
 - a. Conventional concretes made using Types II and V cement show no continuing tendency to increase in length. Increases in lengths were also well below the 0.2 percent generally accepted by the Bureau as indicative of impending failure from sulfate attack. (Complete failure by sulfate attack is considered to be 0.5 percent expansion.)
 - b. The effect of site exposures and laboratory immersion on the lengths of the PIC specimens are shown in figures 12, 13, and 14. The specimens continue to increase in length with duration of exposure. Although much less water is absorbed by the PIC specimens than the two conventional concretes, their increase in length after 22 and 28 months of exposure is of the same order of magnitude as the conventional concretes.
- 3. Surface conditions. Generally, only minor changes in surface appearance have occurred at sites 1 and 2. At site 3, erosion of the surface was experienced as shown in figure 15.
 - a. Concrete made with Type V cement suffered the most severe erosion damage.
 - b. Less severe erosion damage was observed on concrete made using Type II coment.
 - c. PIC was only slightly altered in appearance by the erosion.

TABLE 8a. CONCRETE COMPRESSIVE STRENGTH TEST RESULTS - SITE 1*

its)	
etric unit	

	Nominal		(ave	erage of dup	compressive strength (mra) (average of duplicate specimens)	
Concrete	exposure		Site exposure		Laboratory e	exposure**
type	time, mo.	Gas	Interface	Liquor	50 percent relative humidity, 73°F	Denver tap water, room temperature
Type II cement	***0	·			32.6	
(28 day strengtl	1 - 3	41.6	38.3	38.6	34.1	39.0
31.0 MPa)	10	53.2	48.8	50.0	34.0	40.3
	22	51.6#	53.0#	46°1#	35.3	76.0
Type V cement	***0				31.9	
(28 day strength -	1 - 3	35.6	32.5	33.8	35.2	35.0
29 (0 MPa)	10	46.5	0.94	45.5	40.3	41.4
	22	440.5##	#8.84	45.2#	36.1	42.2
Type II cement	***0				144.1	
polymer	3	123.0	127.8	127.1	151.8	139.1
impregnated###	t 10	115.4	132.9	83.4	132.9	6*66
	22	93.6#	130.0#	114.0#	142.2	114.9

Tapia Water Reclamation Facility, Calabasas, California.

E&R Center Laboratories, USBR, Denver, Colorado.

*** Concrete age when specimens first exposed: 3 months.

* Based on four specimens.

Based on three specimens. ### Strength before impregnation

Strength before impregnation has little effect on final strength, and after impregnation, additional cure time does not increase strength.

TABLE 86. CONCRETE COMPRESSIVE STRENGTH TEST RESULTS - SITE 1*

(English units)

Concrete	Nominal exposure time, mo.	Ses	Com (aver Site exposure Interface	pressive str rage of dupl	Compressive strength (1b/in²) (average of duplicate specimens) ure Laboratory exposure*** 50 percent relative Denver humidity, 73°F room terms	exposure*** Denver tap water, room temperature
Type II cement (28 day strength 4500 lb/in)	0*** - 3 10 22	6,040 7,710 7,490#	5,560 7,080 7,680#	5,600 7,250 7,120#	4,730 4,950 4,930 5,120	5,650 5,850 6,620
Type V cement (28 day strength - 4200 lb/in)	0*** - 3 10 22	5,160 6,740 7,140##	4,720 6,670 7,080#	4,900 6,500 6,550#	4,620 5,110 5,840 5,235	5,080 6,010 6,120
Type II cement polymer impregnated###	0*** 3 10 22	17,840 16,740 13,580#	18,530 19,270 18,860#	18,440 12,090 16,530	20,900 22.010 19,270 20,620	20,170 14,490 16,660

* Tapia Water Reclamation Facility, Calabasas, California,

E&R Center Laboratories, USBR, Denver, Colorado.

*** Concrete age when specimens first exposed: 3 months.

Based on four specimens.

Based on three specimens.

Strength before impregnant

Strength before impregnation has little effect on final strength, and after impregnation, additional cure time does not increase strength.

TABLE 9a. CONCRETE COMPRESSIVE STRENGTH TEST RESULTS - SITE 2* (metric units)

polymer 10 103.1 115.6 106.0 126.7 108.0
--

Speedway Wastewater Treatment Plant, Indianapolis, Indiana.

** E&R Center Laboratories, USBR, Denver, Colorado.

*** Concrete age when specimens first exposed: 8 months.

Based on length change specimen with inserts sawed off, results corrected to length/diameter - 2.0. Strength before impregnation has little effect on final strength, and after impregnation, additional cure time does not increase strength. #

CONCRETE COMPRESSIVE STRENGTH TEST RESULTS - SITE 2* (English units) TABLE 9b.

	Nominal		Con (ave	Сотргеssive strength (average of duplicate	(1b/ spec	
2 3 4 0 0	PATICOLITE		Site exposure		Laboratory exposure	exposure
type	time, mos.	Gas	Interface	Liquor	50 percent relative humidity, 73°F	Denver tap water, room temperature
Type II cement	***0			(13)	3,890	0.59 .5
(28 day strength - 4500 lb/in)	h - 10 28	6,220 6,390#	5,780 5,860#	6,320	5,550	6,570
A Common A	****				4,280	
1ype v cement (28 day strength - 4200 lb/in ²)	7	5,820 5,680#	5,860 5,960#	5,660 6,150#	5,340	5,530
Type II cement	***0			700	20,090	15.670
polymer impregnated##	10	14,950 15,810#	16,760 14,890#	17,170#	15,580	11,240

Speedway Wastewater Treatment Plant, Indianapolis, Indiana.

E&R Center Laboratories, USBR, Denver, Colorado. **

Concrete age when specimens first exposed: 8 months. Based on length change specimen with inserts sawed off, results corrected to length/diameter - 2.0. ***

Strength before impregnation has little effect on final strength, and after impregnation, additional ##

cure time does not increase strength.

TABLE 10a. - CONCRETE COMPRESSIVE STRENGTH TEST RESULTS - SITE 3* (metric units)

	Nominal		(ave	(average of duplicate	erage of duplicate specimens)	
Concrete	exposure		Site exposure		Laboratory	exposure**
type ti	time, mo.	Gas	Interface	Liquor	50 percent relative humidity, 73°F	Denver tap water, room temperature
Type il cement	***0				29.6	
(28 day strength -		41.2	41.8	38.2	31.0	38.45
31.0 MPa)	23	6.74	47.3	45.5	35.2	38.2
	28	45.9#	43.4#	46.1#		
Type V cement	***()				29.8	
(28 day strength -		42.7	40.4	41.3	32.5	37.5
29.0 MPa)		49.1	46.5	48.2	38.5	40.3
	28	#7.67	45.8#	#1.44		
Type II cement	***0				129.8	
polymer	10	116.0	129.2	92.2	118.6	74.5
impregnated##	28	119.9	81.6	89.3	121.7	110.6
	28	112.7#	115.5#	118.4#		

Westgate Wastewater Treatment Plant, Alexandria, Virginia

** E&R Center Laboratories, USBR, Denver, Colorado.

*** Concrete age when specimens first exposed: 8 months.

Based on length change specimen with inserts sawed off, results corrected to length/diameter - 2.0.

Strength before impregnation has little effect on final strength, and after impregnation, additional cure time does not increase strength.

CONCRETE COMPRESSIVE STRENGTH TEST RESULTS - SITE 3* (English units) TABLE 10b.

	ive Denver tap water,	5,580	5,440	10,810
Compressive strength $(1b/in^2)$ (average of duplicate specimens)	Laboratory 50 percent relative humidity, 73°F	4,300 4,500 5,110	4,320 4,720 5,590	18,820 17,200 17,655
mpressive str erage of dupl	Liquor	5,540 6,600 6,680#	5,990 6,990 6,490#	13,370 12,950 17,170#
Co (av	Site exposure Interface	6,060 6,880 6,300#	5,860 6,750 6,640#	18,740 11,830 16,750#
	Gas	5,980 6,950 6,660#	6.200 7,120 7,170#	16,830 17,390 16,340#
Nominal	exposure time, mos.	0*** - 10 28 28	0*** - 10 28 28	0*** 10 28 28
	Concrete type t	Type II cement (28 day strength - 4500 lb/in ²)	Type V cement (28 day strepgth - 4200 lb/in ²)	Type II cement polymer impregnated##

Westgate Wastewater Treatment Plant, Alexandria, Virginia

^{**} E&R Center Laboratories, USBR, Denver, Colorado. *** Concrete age when specimens first exposed: 8 months. # Based on length change specimens with inserts sawed off, results corrected to length/diameter - 2.0. Strength before impregnation has little effect on final strength, and after impregnation, additional cure time does not increase strength. ##

TABLE 11. CONCRETE LENGTH CHANGE TEST RESULTS - SITE 1*

	Nominal		I	ength change	Length change, percent***	
Concrete	exposure		Site exposure		Laboratory exposure#	xposure#
type**	time, mo.	Gas	Interface	Liquor	50 percent relative humidity, 73°F	Denver tap water, room temperature
gand (tan)	3	0.043	0.056	非非	600*0-	0.042
	10	0.050	0.070	0.098	-0.009	0.050
	22	0.022	0.048	0.056	-0.008	0.053
V	3	0.036	0.048	恭非	600*0-	0.035
	10	0.046	0.050	0.076	-0.004	0.037
	2.7	0.041	0.034	0.062	-0.005	0.040
Ā	3	900.0	0.016	##	-0.005	0.003
	10	0.031.	0.036	0.037	0.003	0.021
	22	0.053	0.053	0.050	0.008	0.046

Tapia Water Reclamation Facility, Calabasas, California.

II - Concrete made using type II cement.

V - Concrete made using type V cement.

*** Percent gain (positive values) or loss (negative values) in length as compared to original length determined at time of exposure, average of three replicate specimens. P - Polymer-impregnated concrete made using type II cement.

E&R Center Laboratories, USBR, Denver, Colorado.

Specimens could not be removed from exposure to determine their lengths after 3 months' exposure.

CONCRETE LENGTH CHANGE TEST RESULTS - SITE 2* TABLE 12.

exposure### Denver tap water,	0.046 0.040 0.042 0.028	0.046 0.037 0.045 0.042	0.019 0.021 0.039 0.047
ratory## relative 73°F	0.000 -0.003 -0.002 -0.018	0.001 -0.001 -0.001 -0.021	0.009 0.010 0.015 0.012
Liquor 50 percent*** Liquor 50 percent humidity,	0.051 0.056 0.056 0.054	0.056 0.057 0.053 0.063	0.008 0.013 0.018 0.034
L Site exposure# Interface	0.060 0.066 0.061 0.079	0.053 0.047 0.043 0.054	0.018 0.027 0.043 0.067
Gas	0.051 0.059 0.068 0.068	0.046 0.056 0.063 0.074	0.010 0.028 0.060 0.078
Nominal exposure time, mo.	3 10 20 28	3 10 20 28	3 10 20 28
Concrete type**	II	Δ	<u>ο</u> ,

Speedway Wastewater Treatment Plant, Indianapolis, Indiana

II - Concrete made using type II cement.
V - Concrete made using type V cement.

Percent gain (positive values) or loss (negative values) in length as compared to original P - Polymer impregnated concrete made using type II cement. ***

length determined at time of exposure.

E&R Center Laboratories, USBR, Denver, Colorado. Average of two replicate specimens. ## #

Average of three replicate specimens.

CONCRETE LENGTH CHANGE TEST RESULTS - SITE 3* TABLE 13.

t*** Laboratory## exposure **				0.046			3 0.036			0.011		0.062	
Length change, percent***	50 percent relative humidity, 73°F	0.001	00.0-	-0.007	-0.013	0.005	-0.00	600*0-	-0.012	0.007	0.017	0.011	0.00
Length change	Liquor	0.055	990.0	990.0	0.076	0.056	0.057	0.053	0.063	0.011	0.028	0.043	0.068
L Site exposure#	Interface	0.055	0.065	0.054	++	0.049	0.044	+-	+++	0.023	0.031	0.054	0.081
	Gas	0.059	0.060	090.0	690.0	0.049	0.053	0.053	0.059	0.015	0.029	0.042	0.076
Nominal exposure	time, mo.	Э	10	20	28	3	10	20	28	9	10	20	28
Concrete	type**	p-1 p-1				Λ				Q.			

Westgate Wastewater Treatment Plant, Alexandria, Virginia

II - Concrete made using type II cement.

V - Concrete made using type V cement.

P - Polymer-impregnated concrete made using type II cement. Percent gain (positive values) or loss (negative values) in length as compared to original ネャネ

length determined at time of exposure.

Average of two replicate specimens.

E&R Center Laboratories, USBR, Denver, Colorado.

Average of three replicate specimens. ###

Embedded metal inserts were loosened by exposure such that length determination could not be made.

TABLE 14. CONCRETE LENGTH CHANGE TEST RESULTS -LABORATORY* EXPOSURES

					t change#	
_	Control	Nominal		ercent	Denve	r tap water
Concrete	specimens	exposure		ty, 73°F	room to	emperature
type**	for site***	time, mo.	Grams	Percent	Grams	Percent
		3	-3.7	-0.24	57.7	3.80
	1	10	-1.0	-0.07	61.4	4.04
		22	2.3	0.15	62.5	4.12
		3	1.0	0.06	68.2	4.49
II	2	10	3.0	0.19	• 71.4	4.70
		20	4.0	0.26	71.5	4.70
		28	7.7	0.50	73.7	4.85
		3	0.9	0.06	70.2	4.62
	3	10	2.6	0.17	73.6	4.84
		20	3.9	0.26	74.0	4.87
		28	7.3	0.48	76.0	5.00
		3	-4.8	-0.32	57.0	3.70
	1	10	-2.6	-0.17	59.8	3.88
		22	1.3	0.08	61.3	3.97
		3	2.6	0.17	65.6	4.24
V	2	10	4.7	0.31	66.6	4.31
		20	6.6	0.43	67.0	4.33
		28	10.0	0.66	69.0	4.46
		3	0.6	0.04	67.1	4.37
	3	10	2.6	0.17	69.2	4.51
		20	3.8	0.24	69.5	4.52
		28	7.3	0.48	71.8	4.68
		3	-1.7	-0.11	11.3	0.71
	1	10	0.0	0.00	12.4	0.78
		22	2.4	0.14	18.1	1.14
		3	1.2	0.08	9.9	0.62
P	2	10	1.9	0.12	17.4	1.10
		20	1.9	0.12	20.2	1.27
		28	3.8	0.24	23.2	1.46
		3	0.6	0.04	11.4	0.72
	3	10	1.4	0.09	15.0	0.94
		20	1.2	0.07	17.0	1.07
		28	4.0	0.25	20.7	1.30

^{*} E&R Center Maboratories, USBR, Denver, Colorado.

^{**} II - Concrete made using type II cement.

V - Concrete made using type V cement.

P - Polymer-impregnated concrete made using type II cement.

^{*** 1 -} Tapia Water Reclamation Facility, Calabasas, California

^{2 -} Speedway Wastewater Treatment Plant, Indianapolis, Indiana

^{3 -} Westgate Wastewater Treatment Plant, Alexandria, Virginia

[#] Gain (positive values) or loss (negative values) in grams and percent based on the original weight determined at time of exposure.

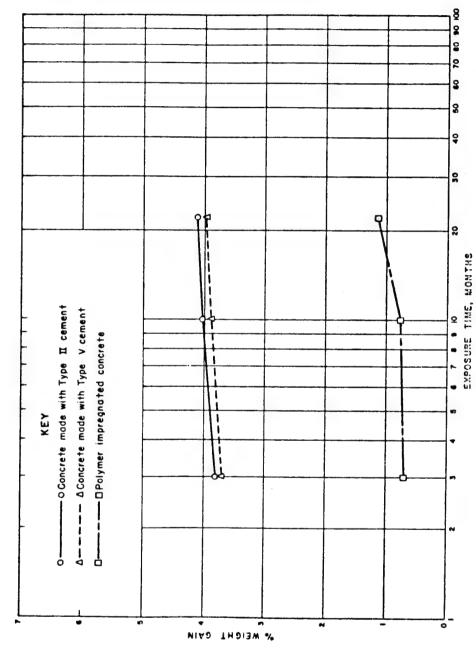


FIGURE 9. EFFECT OF IMMERSION IN DENVER TAP WATER ON ABSORPTION BY SITE I CONCRETE CONTROL SPECIMENS

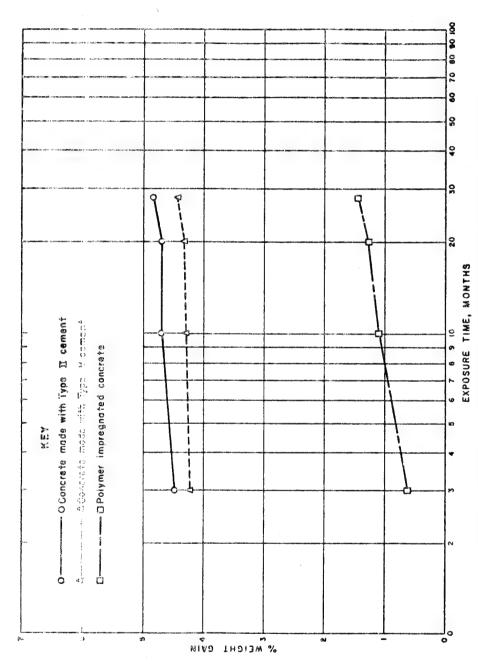


FIGURE 10. EFFECT OF IMMERSION IN DENVER TAP WATER ON ABSORPTION BY SITE 2 CONCRETE CONTROL SPECIMENS

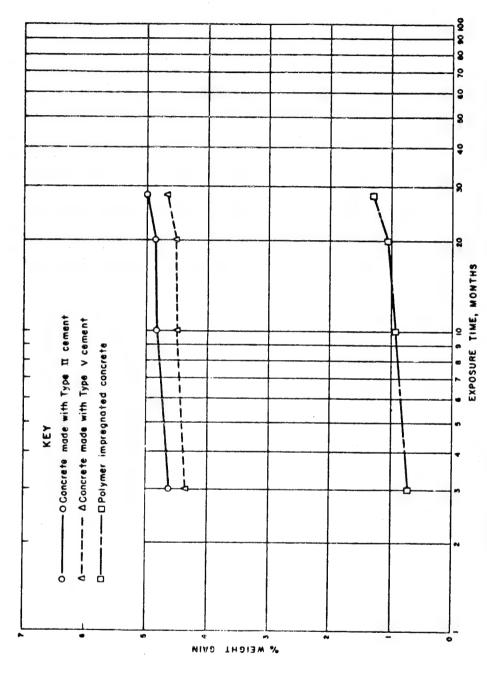


FIGURE II. EFFECT OF IMMERSION IN DENVER TAP WATER ON ABSORPTION BY SITE 3 CONCRETE CONTROL SPECIMENS

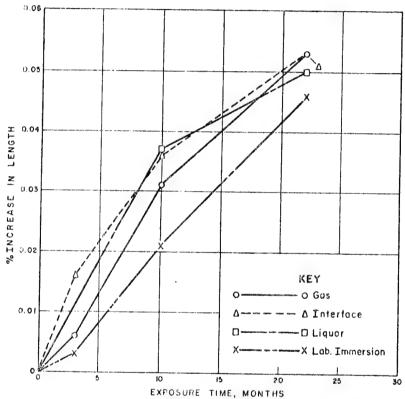


FIGURE 12. EFFECT OF SITE I EXPOSURE AND LABORATORY IMMERSION EXPOSURE ON LENGTH OF POLYMER IMPREGNATED CONCRETE

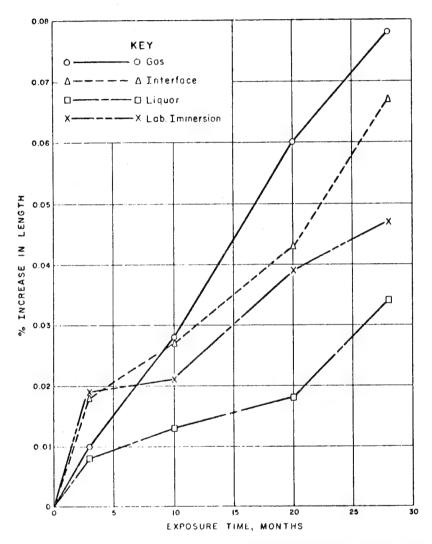


FIGURE 13. EFFECT OF SITE 2 EXPOSURES AND LABORATORY IMMERSION ON LENGTH OF POLYMER IMPREGNATED CONCRETE

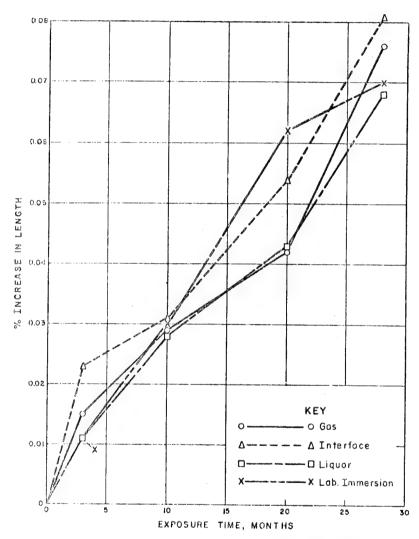


FIGURE 14 EFFECT OF SITE 3 EXPOSURES AND LABORATORY IMMERSION EXPOSURE ON LENGTH OF POLYMER IMPREGNATED CONCRETE

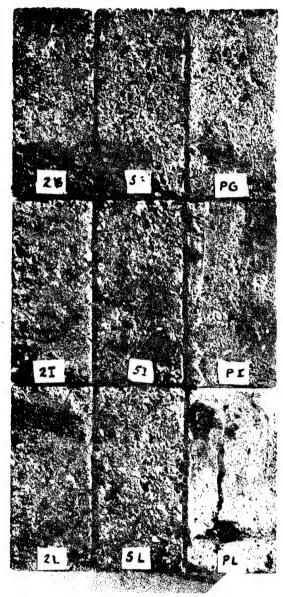


Figure 15. - Concrete prisms emposed at site 3 for 28 months depict the damage due to surface abrasion. Prefix of specimen code denotes concrete type, i.e., 2-Type II, 5-Type V, and P-PIC; suffix indicates exposure, i.e., G-gas, I-interface, L-liquor.

Steel Embedded in Concrete

These results are listed in tables 15, 16, and 17. The corrosion rates of steel embedded in concrete, as determined by steel-to-electrolyte potentials and polarization tests and as verified by visual examination of the steel after removal of the concrete cover at the end of the test, were found to be so low as to be insignificant.

Alloys

1. Unstressed specimens. - Average corrosion rate, maximum pit depth, and crevice corrosion results appear in tables 18, 19, and 20. The evaluation of the data has been summarized in table 21. Alloys were evaluated by assigning ratings based on their overall performance in all three exposure zones of all three test sites. The ratings were assigned in accordance with criteria shown in the table below:

Average corr	osion rate (x)	Maximum pitt	ing rate (y)	Rating
un/yr	mils/yr	μm/yr	mils/yr	
x<3 3≤x<25 25≤x<254 x≥254	x<0.1 $0.1 \le x<1.0$ $1.0 \le x<10.0$ $x \ge 10.0$	y<3 3≤y<25 25≤y<254 y <u>></u> 254	y<0.1 0.1 <y<1.0 1.0<y<10.0 y>10.0</y<10.0 </y<1.0 	1 2 3 4

Figures 16 through 21 show typical corrosion of exposed specimens.

The alloys are rated as follows according to their performance in all three exposure zones at the three test sites:

- a. Highly resistant (rating of 1.0)
 - (1) Stainless steel, Type 201 (Alloy A-4)
 - (2) Stainless steel, Type 304 (Alloy A-5)
 - (3) Stainless steel, Type 316 (Alloy A-7)
- b. Moderately resistant (1.0 < rating \leq 2.0)
 - (1) Sensitized stainless steel, Type 304 (Alloy A-6).
 - (2) Sensitized stainless steel, Type 316 (Alloy A-8)
- c. Resistant (2.0 \leq rating \leq 3.0)
 - (1) Nickel cast iron (Alloy A-9)
 - (2) Deoxidized copper (Alloy A-10)
- d. Nonresistant (rating > 3.0)
 - (1) Gray cast iron (Alloy A-1)
 - (2) Mild steel (Alloy A-2)

TEST RESULTS - STEEL EMBEDDED IN CONCRETE - SITE 1* TABLE 15.

Concrete type**	Nominal exposure	Steel-to-	Steel-to-electrolyte potential*** volts	ntia1***	Cor (gra	Corrosion rate $\#_4$	7# 01
	time, mo	Gas	Interface	Liquor	Gas	Interface	Liquor
II	· m	-0.11	-0.11	-0.25		1	
	10	90.0-	-0.09	-0.05	1	1	ı
	22	-0.26	60.0-	-0.30	1	ı	ı
Δ	3	-0.12	-0.08	-0.16	ı	ı	,
	10	-0.14	-0.02	-0.12	1	1	ı
	22	-0.07	-0.12	-0.11	1	I	ı
Ωų	8	-0.11	-0.16	-0.11	ı	ı	1
	10	-0.39	-0.17	-0.22	42	1	ı
	22	-0.41	60.0-	60.0-	116	ı	ŀ

Tapia Water Reclamation Facility, Calabasas, California.

II - Concrete made using type II cement.
V - Concrete made using type V cement.
P - Polymer-impregnated concrete made using type II cement.

*** Referenced to copper/copper-sulfate electrode.

* As determined by polarization tests which were conducted only on those specimens exhibiting potentials more negative than -0.30 volt.

TEST RESULTS - STEEL EMBEDDED IN CONCRETE - SITE 2* TABLE 16.

Concrete type**	Nominal exposure	Steel-to-	Steel-to-electrolyte potential*** volts	cential***	0 0	Corrosion rate #	# 0
	time, mo	Gas	Interface	Liquor	Gas	Interface	Liquor
} }	cv	ù					
į) <u>-</u>	-0.04	-0.51	77.0-	133	277	242
	10	-0.11	-0°19	-0.36	ı	ŧ	23.6
	20	-0°08	-0.21	-0.20	ı	ı	7
	28	-0.05	-0.19	-0.14	ı	,	1 1
:							l
À	m	-0.63	-0.50	-0.53	215	360	270
	10	-0.29	-0.13	-0.22	3 1	000	2/0
	20	-0.05	-0.20	-0.23	ı	! :	ł
	28	-0.05	-0.11	-0.19		i	i
f	•						
7 4	က	-0.45	-0.54	-0.36	Y	124	۷,
	10	-0.22	-0.40	-0.28	1	132	} 1
	20	-0.16	-0.26	-0.23	•	101	
	28	-0.08	=0 26			ı	ı
		•	0.40	-0.43		ı	216

Speedway Wastewater Treatment Plant, Indianapolis, Indiana,

II - Concrete made using type II cement.
 V - Concrete made using type V cement.
 P - Polymer-impregnated concrete made using type II cement.

*** Referenced to copper/copper-sulfate electrode.

As determined by polarization tests which were conducted only on those specimens exhibiting potentials more negative than -0.30 volt.

TEST RESULTS - STEEL EMBEDDED IN CONCRETE - SITE 3* TABLE 17.

II 3 -0.49 -0.48 -0.49 -0.49	Concrete c	Nominal xposure	Steel-to-e	Steel-to-electrolyte potential***	ential***	0 8	Corrosion rate #4	# t
3 -0.49 -0.48 10 -0.42 -0.33 20 -0.20 -0.17 28 -0.28 -0.17 3 -0.48 -0.46 10 -0.40 -0.39 20 -0.20 -0.18 28 -0.11 -0.10 3 -0.50 -0.52 10 -0.32 -0.38 20 -0.32 -0.38 20 -0.32 -0.38	,	ime, mo.	Gas	Interface	Liquor	Gas	Interface	Liquor
10	I)	3	-0.49	87°0-	67.0-	103	3,6	103
20		10	-0.42	-0.33	-0.41	100	55 54	67
28 -0.28 -0.17 3 -0.48 -0.46 10 -0.40 -0.39 20 -0.20 -0.18 28 -0.11 -0.10 3 -0.50 -0.52 10 -0.32 -0.38 20 -0.19 -0.24 28 -0.20 -0.33		20	-0.20	-0.17	-0.27) 1	÷ 1	٠ ا
3 -0.48 -0.46 10 -0.40 -0.39 20 -0.20 -0.18 28 -0.11 -0.10 3 -0.50 -0.52 10 -0.32 -0.38 20 -0.19 -0.24 28 -0.30		28	-0.28	-0.17	-0.27	t	1	ı
10 -0.40 -0.39 20 -0.20 -0.18 28 -0.11 -0.10 3 -0.50 -0.52 10 -0.32 -0.38 20 -0.19 -0.24 28 -0.20 -0.33	Λ	ю	-0.48	97.0-	-0.50	36	18	77
20 -0.20 -0.18 28 -0.11 -0.10 3 -0.50 -0.52 10 -0.32 -0.38 20 -0.19 -0.24 28 -0.20 -0.33		10	-0.40	-0.39	-0.44	46	95	86
28 -0.11 -0.10 3 -0.50 -0.52 10 -0.32 -0.38 20 -0.19 -0.24 28 -0.20 -0.33		20	-0.20	-0.18	-0.22	1	1))
3 -0.50 -0.52 10 -0.32 -0.38 20 -0.19 -0.24 28 -0.20 -0.33		28	-0.11	-0.10	-0.19	1	ı	ı
-0.32 -0.38 -0.19 -0.24 -0.20 -0.33	Ь	ന	-0.50	-0.52	-0.52	14	\c	ý
-0.19 -0.24 -0.20 -0.33		10	-0.32	-0.38	-0.36	10	9,8	96
-0.20		20	-0.19	-0.24	-0.23	1	· ·	2
•		28	-0.20	-0.33	-0.47	1	87	186

Westgate Wastewater Treatment Plant, Alexandria, Viriniga. *

II - Concrete made using type II cement.

V - Concrete made using type V cement.

P - Polymer-impregnated concrete made using type II cement.

*** Referenced to copper/copper-sulfate electrode.

As determined by polarization tests which were conducted only on those specimens exhibiting potentials more negative than -0.30 volt.

TABLE 18a. TEST RESULTS - ALLOYS - SITE 1 $\underline{1}/$ (metric units)

A110y 2/	T T T T T T T T T T T T T T T T T T T		(15/EII)			Exposed surface	200		CLANIGE N	1
800 800 800	time (no)	3	Interface	Liquor	Gas	Interface	Liquor	9 9 0	Interface	Liguor
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	22	140	9.00	59	101	89	122	124	51	មា
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	23	152	98	114	251	130	201	142	=	3
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A-3	m	16	8	9 (901	919	3	Š	Theintent	147
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	22	30	20	15	98	33	69	5	ç	7
;	•	•	•	001	1331	1820	2682	٧3	×3	(P)
A-11	~	0	611	7	1361	1001	Pan Court ad		•	3
	9	13	104	5	1000		Tel Tol Bear			245

1/ Tapia Water Reclamation Facility, Calabasas, California $\overline{2}/$ See table 2 for alloy identification. $\overline{3}/$ Surface beneath teflon space.

TABLE 18b. TEST RESULTS - ALLOYS - SITE 1 $\underline{1}/$

(English units)

A-1 10 22 A-4 10 4-4 10 4-7 10 4-7 10 6 22 A-4 10 6	2.6 2.7 5.5 5.5 5.7 5.0 6.0 6.0 6.0 6.0 6.0 6.0 6.0 6.0 6.0 6	(adds/year) Interface 3.5 1.6 4.3 2.1 3.4 1.9 2.5 6.1 60.1 60.1	1.0 2.7 2.4 2.3 4.4 2.3 4.5 5.5 4.5 6.1 6.1 6.1 6.1 6.1 6.1 6.1	28.0 14.4 15.8 36.0 30.0	Exposed surface Interface 14.0	surface face Liquor Gas	Cas	Crevice 3/ Interface	Liquor Liquor
	2.6 2.7 2.7 2.7 2.7 2.7 3.0 3.0 3.0 4.9 6.1 6.1 6.1 6.1 6.1 6.1 6.1 6.1 6.1 6.1	1.5 1.6 1.6 1.2 2.1 3.4 1.9 2.5 6.1 60.1 60.1	Lidgeor 2.4 2.4 2.7 2.7 2.3 4.5 4.5 4.5 6.1 6.1 6.1 6.1 6.1 6.1	0.00	Interface 14.0		Sag	Interface	Liquor
	2.6 2.7 5.5 5.7 5.7 5.0 5.0 6.0 6.0 6.0 6.0 6.0 6.0 6.0 6.0 6.0 6	0.11 0.5 0.1	2,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4	28.0 14.4 15.8 36.0 30.0	14.0				
	2.7 5.7 5.7 5.7 5.0 6.0 6.0 6.0 6.0 6.0 6.0 6.0 6.0 6.0 6	1.6 1.2 2.1 2.1 2.1 3.4 6.1 6.1 6.1 6.1 6.1	60.11.08.00.11.09.00.10.00.11.09.00.10.00.11.09.00.10.00.11.09.00.00.11.09.00.11.09.00.11.09.00.11.09.00.11.09.00.11.09.00.11.09.	14.4 15.8 36.0 30.0 9.9		17.0	× 0.1		. 6 .
	5.5 5.7 5.7 5.0 6.0 6.0 6.0 6.0 6.0 6.0 6.0 6.0 6.0 6	1.2 2.1 2.1 3.4 1.9 6.1 6.1 6.1 6.1 6.1 6.1	2.7 2.4 4.5 4.5 4.5 7.0 7.0 6.1 6.1 6.1 6.1	36.0 30.0 9.9	6.0	6.0	× 0.1		, v
	6.0 6.0 7.2 6.0 6.0 6.0 6.0 6.0 6.0 6.0 6.0 6.0 6.0	4,3 2,1 3,4 1,9 6,1 6,1 6,1 6,1 6,1	60.11 60.11 60.11 60.11 60.11 60.11	36.0 30.0 9.9	3.5	4.8	6.4	2.0	9.0
	\$5.7 6.0 6.1 6.0 1.0 6.1 6.0 1.0 6.1 6.0 1.0 6.1 6.0 1.0 6.1 6.0 1.0 6.1 6.0 1.0 6.0 1.0 6.0 1.0 6.0 1.0 6.0 1.0 1.0 6.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1	2.1 3.4 1.9 60.1 60.1 60.1 60.1	2.3 4.5 1.0 2.0 2.0 6.1 6.1 6.1 6.1	30.0 9.9	20.0	24.0			
	6.0 6.0 6.0 6.0 6.0 6.0 6.0 6.0 6.0 6.0	3.4 1.9 2.5 2.5 6.1 6.1 6.1 6.1	60.11.00 60.11.00 60.11.00	6.6	0.9	4	7.0	7.0	7.5
	\$5.0 \$5.0 \$6.1 \$6.1 \$6.1 \$6.1 \$6.1 \$6.1 \$6.1 \$6.1	1,4 1,9 2,5 6,1 6,1 6,1 6,1	11.8 2.0 2.0 2.0 60.1 60.1 60.1		5.1	7.9	5.6	2.8	• · · ·
	\$ 60.1 60.1 60.1 60.1 60.1 60.1 60.1	1,9 2,5 6,1 6,1 6,1 6,1	60.1 60.1 60.1 60.1 60.1	46.0	11.4	6		•	
	\$.00.1 \$0.1 \$0.1 \$0.1 \$0.1 \$0.1 \$0.1 \$0.	60.1 60.1 60.1 60.1 60.1	2.0 2.0 60.1 60.1 60.1	9 4	10.0	0.07	1.0 >	₹ 0.1	× 0.1
	60.1 60.1 60.1 60.1 60.1	60.1 60.1 60.1 60.1 60.1	60.1 60.1 60.1 60.1	9.6	6.5	5.1	3.0	Incipient	3.4
	0 0 0 0 0	\$00.1 \$0.1 \$0.1 \$0.1 \$0.1 \$0.1 \$0.1 \$0.1			,				
	\$ \$ \$ \$ \$ \$		60.1.	* 0°1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	6 66.1	60.1 60.1 60.1 60.1	60.1		< 0.1	₹ 0.1	< 0.1	< 0.1	< 0.1
	60.11	<0.1 <0.1 <0.1	40.1	1.0 >	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	60.1	<0.1 <0.1	40.1	100					,
	c0.1	<0.1			, v	1.00	.0.1	4 0.1	< 0.1
	*0.1					1.0	1.0 >		< 0.1
	*0.1		•	1.0	1.0	1.0	< 0.1	* 0.1	< 0.1
		<0.1	<0.1	< 0.1	< 0.1			•	
	<0.1	*0.1	<0.1	3.0	¢ 0,1	, v			7.0
	c0.1	*0.1	<0.1	9.0	< 0.1	< 0.1	< 0.1	4 0.1	
	,	•	,					:	
	7.0	40.1	*0.1		< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	1.0	1.0.	1.0		< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	1.02	1.0	40.1	• 0.1	4 0.1	< 0.1	< 0.1	< 0.1	€ 0.1
01 6	€0.1	<0.1	1.0>				•		
"	<0.1	<0.1	<0.1				1.0	7.0 ,	10,
77	<0.1	c0.1	<0.1	3.6	< 0.1		, v	7.0	1.0
-	,	-	•		;			•	•
		2.4	1.	0.01	12.0	0.9	< 0.1	< 0.1	< 0.1
33		•		7.01	0	12.0	< 0.1	< 0.1	< 0.1
i	•	:	7.7	٠.	•	9.4	< 0.1	2.7	2.1
A-10 3	1.2	1.5	1.3	< 0.1	< 0.1	12.0	. 0 >		
10	1.1	1.0	6.0	9.0	2.4	00			
22	1.2	8.0	2.0	3.4	1.3	2.7	< 0.1	4 0.1	, O.1
4-11	•	,		;					
01			2.1	52.0	72.0	104.0	< 0.1	< 0.1	< 0.1
33	9	7.7		39.0	43.2	Perforated	Perforated	37.8	33.6
i	000	7:7		FETTOTACOL	18.7	Perforsted	Parforated	12.3	13.7

1/ Tapis Water Reclamation Facility, Calabases, California, $\frac{2}{3}$ / See table, 2 for alloy identification, $\frac{3}{3}$ / Surface beneath teflor apacer,

TABLE 19a. TEST RESULTS - ALLOYS - SITE 2 $\underline{1}/$ (metric units)

Name (Eq.) Class Interface Liquor (Ras Liquor (Ras Interface Liquor (Ras Liquor (Ras Interface Liquor (Ras Liquor (Ras	code	Sansodae	2	Average corrosion rate (un/yr)	0232		Exposed surface	Haximum pitting rate (pm/yr) face	ng rate (ya/yr) Crevice 3/	
3 99 20 107 43 43 43 43 43 43 43 4	ño.	time (Eo)	Gas	Interface	Liquor	Gaa	Interface	Liquor	Gas	Interface	Liquor
10	-	m	9.	20	107	65	<3	\$\$	6	63	63
28 165 168 221 01. 345 355 100 29 69 46 97 702 104 1457 119 29 97 20 84 1860 231 01. 104 1457 119 20 98 46 77 175 175 170 104 1457 119 20 98 47 175 175 170 104 1457 119 20 98 47 175 175 170 104 1457 119 20 63 63 63 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 63 63 63 63 20 63 63 63 63 63 63 63 63 63 63 63 63 63		- 13	22	7.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00	72 92 14	0.55	000	1220	ŋ	17	tu un mi
1,05		28	90	168	221	සි	345	386	೦೧೭	en ∨	130
10 6.9 46 97 762 747 447 195 110 110 110 110 110 110 110 110 110 11	6-3	m	165	20	81	3016	965	762	5 57	A box	67
26 61 179 119 127 142 104 147 119 119 119 119 119 119 119 119 119 11		10	ර්	32	26	762	上計画	157	361	163	300
28 48 1880 258 610 457 29 77 18 163 533 657 28 48 1880 258 610 457 28 48 178 163 533 633 63 63 63 63 63 63 63 63 63 63 63		23	Ç.	74	127	142	104	147	O THE	107	193
28 48 77 18 163 533 157 549 213 28 48 77 18 163 533 157 549 213 28 48 77 18 163 533 54 54 52 54 54 54 54 54 54 54 54 54 54 54 54 54	B-8	(7°)	66	20	88	1880	254	610	(f) V	es.	100
28 46 75 100 Perforehed Perforehed 275 100 100 Perforehed 275 100 100 Perforehed 275 100		10	26	e) P=	163	533	255		213	101	ig (
28		28	187 120	\$\frac{1}{2}	25	180	Perforated		5	51	F/A V
28	esp.	en ;	Ç	en V	చ	\$	ς. (Σ)	(87) V	Ç	ea V	(S)
28		ន្ទទ	က္စ (၃	*	(P)	5	(C)	(%) V	S)	· 63	i RO
28		97	V	ΰ	5	Ç	(3)	Ŋ	ŋ	Ą	₹7) V
26	5	8	ŝ	m V	150	φ.	(17) V	6	177) V	6	8
28		2	ŋ	€	ry.	ę,	₩,	(ମ V	۲ ۷	7	1 (M)
3 \$\langle 3\$ \$\langle 3\$ <td></td> <td>22</td> <td>ņ</td> <td>€</td> <td>₽</td> <td>φ,</td> <td>₽ ·</td> <td>m) ∨</td> <td>ę,</td> <td>m</td> <td>(P)</td>		22	ņ	€	₽	φ,	₽ ·	m) ∨	ę,	m	(P)
26	9	en j	ΰ	e,	۵	â	67) V	•	en V	53	FV?
3 43 43 43 43 43 43 43 43 43 43 43 44 43 44 43 43		10 80 80	Ç,	<u>ښ</u> ز	~	ښ.	<u>ښ</u> (ان	ΰ,	6	v
3 43 <t< td=""><td></td><td>3</td><td>2</td><td>?</td><td>0</td><td>\$</td><td>77)</td><td>₹ V</td><td>Ş</td><td>8</td><td>~</td></t<>		3	2	?	0	\$	77)	₹ V	Ş	8	~
28	~	mç	ψţ	ΰ,	ΰ,	ا	\$	φ,	φ,	\$	የ/ጎ V
3 <3 <3 <3 <3 <3 <3 <3 <3 <3 <3 <3 <3 <3		82	, .	20	20	20	KU (M) ∧ ∧	Makea V V	()	₩ ₩ V	en ed
10 <3	4	m	6	Ę	٢	~	0	,	,	,	. e
28 <3 <3 <4 <3 <5 <3		10	ψ) (m) V	, ŵ) (e) / V) (M	7 en	? ♡	Ç 😲	9 (% V
3 33 23 13 1067 1219 711 <3		5 8	ΰ	ç	£	₩	ů	Ş	i fri V) (Ç)	ក្ន
10 %1 33 23 335 366 244 196 26 26 26 26 26 26 26 26 26 26 26 26 26	ණ ද	m	(P)	(A)	13	1067	0125	78.3	P7	1219	67
3 5 10 33 63 63 63 63 63 63 63 63 63 63 63 63		10	<u> </u>	S	EN I	335	366	27	368	320	9 (0°) 1 Y
3 5 10 33 43 43 43 5 3 43 43 1067 43 10 143 15 10 143 15 43 15 43 10 143 15 671		200	Ş	~박 만	33	C:	16	ග න	160	81	(P) V
10 5 5 1 43 43 43 43 43 43 43 43 43 43 43 43 43	-10	m	រក	2	33	ŝ	€, (5)	en V	64 V	65 V	697. ∀
20 3 15 33 168 6 46 <3 3 <3 <3 <3 <3 <3 3 3 10 143 152 671 <3		2 6	<u>ب</u>	S.	Z,	V Post	777 V	Ç	۳ŋ ۷	€7\ V	6 η ∨
3 <3 <3 <3 <3 <3 <3 1067 <2 10 1433 152 671 <3		9	77	15	33	168	ග	60 #F	۳٦ ٧	¢3	(2)
3 <3 10 1433 152 671 <3	-13	m	φ,	Φ,	£	\$	es. >	1067	63	6	65
		23	m i	ç		1433	152	671	6	V	্বল ১

1/ Speedway Wastewater Treatment Plant, Indianapolis, Indiana. $\frac{2}{3}$ / See table 2 for alloy identification. $\frac{3}{3}$ / Surface beneath teflon spacer.

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TABLE 19b. TEST RESULTS - ALLOYS - SITE 2 $\underline{1}/$ (English units)

Code 40	STROUGHT S	AM	Average corrosion rate (mils/vest)	rate		Exposed surface	ourface	7	Creetce 3/	
	time (mo)	Çus	Interface	Liquor	Gas	Interface	Liquor	Ses	Interface	Liquor
1-1	,	3.6	8.0	4.2	< 0.1	< 0.1	< 0.1	<0.1	< 0.1	< 0.1
1	10	3.9	4.4	9.6	15,6	15.6	50.4	<0.1	< 0.1	6.0
	28	2.3	9.9	8.7	3.2	13.6	15.2	7.1	< 0.1	5.1
7-7	•	6.5	6.0	3.2	40.0	38.0	30.0	<0.1	< 0.1	< 0.1
	, 5	2.7			30.0	20.4	13.0	7.3	6.6	14.4
	38	2.4	6.	5.0	5.6	1.1	3,8	6.3	4.3	7.6
A- 3	en		8.0	3,3	74.0	10.0	24.0	1.00	< 0.1	< 0.1
,	=		0	4.4	21.0	18.0	21.6	-d	4.2	< 0.1
	28	9	. 63	3.8	7.3	Parforeted	Perforated	6.9	2.0	< 0.1
1	m	<0.1	40.1	<0.1	< 0.1	< 0.1	< 0.1	40.1	△ 0.1	< 0.1
,	9	100	100	40.1	4 9.1	× 0	× 0.1	40.1	× 0.1	4 0.1
	8	40.1	40.1	40.1	4 0.A	4 0.1	< 0.1	*0.1	₹ 0.1	< 0.1
5-1	-	<0.1	1.0	<0.1	< 0.1	4 0.1	₹ 0°7	<0.1	A 0.1	٠ ٥٠,٥
	9	40.1	40.1	<0.1	¢ 0.1	× 0.1	× 0.	40.1	4 0.1	A 00.1
	23	40.1	<0.3	<0.1	< 0.1	4.0	× 0.5	<0.1	< 0.1	< 0.1
1	•	£0.3	40.1	<0.1	< 0.1	< 0.1	< 0.1	€.	< 0.1	< 0.1
•	91	4.0.1	40.1	40.1	4 0.1	< 0.1	c 0.1	40.1	< 0.1	< 0.1
	38	€0.1	40.1	<0.1	< 0.1	< 0.1	< 0.1	<0.1	C 9.1	€ 0.1
1	eq	£0.3	<0.1	40.1	4 0.1	× 0.3	< 0.1	<0.	< 0.1	< 0.1
	9	60.1	*0.1	<0.1	< 0.1	< 0.1	₹ 0.1	<0.1	₹ 0.1	< 0.1
	28	c0. 3	<0.1	<0.1	< 0.3	< 0.1	₹ 0.1	40.1	< 0.1	₹ 0.1
8-4	e	*0.1	<0.1	40.1	< 0.1	< 0.1	< 0.1	<0.1	< 0.1	< 0.1
	10	*0. 1	<0.1	<0.1	¢ 0.1	< 0.1	< 0.1	*0.1	< 0.1	< 0.1
	28	<0.1	<0.1	40.1	< 0.1	< 0.1	₹ 0.1	<0.1	< 0.1	* 0.1
£.9	m	1,3	6.0	0.5	0.04	48.0	28.0	<0.1	48.0	4 0.1
	10	1.6	1,3	0.9	13.2	14.4	9.6	7.8	12.6	< 0.1
	28	1.2	1.6	1.5	5.6	0.7	1.9	6.3	3.2	₹ 0.1
A-10	m	0.3	4.0	1.3	< 0.1	< 0.1	< 0.1	40.1	< 0.1	< 0.1
	10	0.3	0.2	2.0	< 0.1	< 0.1	· 6.1	c0.1	< 0.1	4 0.1
	28	0.1	9.0	1.3	9.9	0.3	1.9	<0.1	< 0.1	< 0.1
4-11		<0.1	<0.1	<0.1	< 0.1	< 0.1	42.0	<0.1	< 0.1	¢ 0.1
1	91	0.1	<0.1	4.0	56.4	0.9	36.4	<0.1	< 0.1	< 0.1
	28	0.2	<0.1	1.9	Perforated	2.6	Perforated	9.0	6.7	* 0.1

1/ Speedway Wastewater Treatment Plant, Indianapolis, Indiana. $\frac{2}{3}$ / See table 2 for alloy identification. $\frac{3}{3}$ / Surface beneath teflon spacer.

TABLE 20a. TEST RESULTS - ALLOYS - SITE 3 $\underline{1}$

A1109 2/	Mostral	Ave	Average corrosion rate	in mite		¥	Maximum oftting mate (um/vr)	Inc rate (un/ve)	
ති ර	expoeure		(ng/yr)			Exposed surface	90		Crevice 3/	
.go.	time (20)	Cas	Interface	Liquor	Gas	Interface	Liquer	Ges		1.18
er:	ger i	2.5	38	6	ć,	6,	6.7	ů,	6,	,
	9	(E)	£.	132	ŵ	\$	000	196	525	, A
	26	M	76	44	15	7.1	23	16	112	V
A-2	m	33	118	76	610	157	305	Ü	Ç	A
	ខ្ល	9,	98	46	183	366	198	335	327) (M
	8	52	100	8	ලා ආ	752	61	160	173	S
A-3	m	30	107	11	457	305	559	5	P. V	
	2 5	88	en i	9 6	152	91	381	36.	213	7 23
	8	3	7	2	61	191	107	168	109	137
1	m	ŋ	63	(c)	6.	€,	Ü	Ç	۲	Ç
	28	φ,	۵,	ê.	ů	. (Ç)	<u>ښ</u>	۵,	9	7 (5)
	R	7	¢9	Φ.	φ.	Š	ę,	۵	φ.	. 6
8-8	m	ů	<3	8	ņ	¢3	6	Ş	₩	A
	ឧទ	ტ (۵,	₽	Φ.	φ,	~	, Φ	9	9 (*) V
	ę	ņ	Ę	Ψ,	Û	ô	Ţ	û	€7 V	V
9	m	Û	€	\$	6	8	5	5	,	,
	2	û	ô	۵	. ₽	, ψ	, e) er	7 8	n 67 / V
	22	Û	6	û	û	φ.	Ç	۵.	, £,	۵,
1-1	m	ŝ		5	Ç	8	ç	ç	. 5	,
	2	Φ,	Ç	~	9	* (P)	, C	7) K	7 (P)
	28	ņ	\$	ξ,	Ç	M	Ψ.	(A)) (V)	, 6.
A-6	m	۵	\$°	Ş	60	(° V	(°	60 V	Ç	;
	2 %	ψ,	₩,	~	у М	V 60	, &,	ာ ဇွာ	° \$	n (P)
	0	\$	₩	Φ.	(7) V	₩ V	A 62	6 0	€? V	~
A-9	m	8	60	18	302	A	8	60 V	60 Y	Ç
	2	81	33	10	213	125	273	122	Î (9	7) (F) V
	8	01	30	m	S	15	92	26	ន	Š
A-10	m	©	18	23	\$	6	€0°	F >	7	(F)
	0 g	ω e	æ (8	₩.	**************************************	, en	A 1 (A)	A 603) (P)
	3	0	Ş	9	10 13°	49	ምነ V	ట	\$	Ą
A-13	ണട്ട	en (m	₩,	596	~	en V	~	Ş	ν (γ)
	\$ 62 50 50 50 50 50 50 50 50 50 50 50 50 50	n (n) ()		223	7 4 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6	970 970	18 C	198 8	ล็
				,				2	Sec	4

1/ Westgate Wastewater Treatment Pient, Alexandria, Virginia. 2/ See table 2 for alloy identification. 3/ Surface beneath teflon spacer.

TABLE 20b. TEST RESULTS - ALLOYS - SITE 3 1/

(English units)

A1109 2	Nominal	AWE	Average corresion rate (mile/ver)	Lace .		Exposed surface		urface	Crevice 3/	
ż	time (mo)	Cas	Interface	Liquor	Cass	Interface	Liquor	Cass	Interface	Liquor
1	-	2.0	3.4	2.7	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	٠٥.1
•	10	0.7	1,7	5.2	< 0.1	< 0.1	19.2	7.8	0.6	¢0.1
	28	0.5	3.0	1.6	9.0	2.8	6.0	3.6	4.4	60.1
7-7		1.3	4.5	3.0	24.0	18.0	12.0	< 0.1	< 0.1	<0.1
	, 5	1	· •	1	7.7	14.4	7.8	13.2	13.8	40.1
	2 82	1.0	3.2	1.3	1.9	10.1	2.4	6.3	8.9	2.1
1		1.2	4.2	2.8	18.0	12.0	22.0	< 0.1	< 0.1	<0.1
,	, 5	1 2		2.7	0 9	3.6	15.0	10.3	9. 8	4.8
	28	6.0	2.0	1:1	2.4	7.5	4.2	9.9	4.3	5.4
è		1.05	1.0	40.1	* 0.3	< 0.1	< 0.1	< 0.1	< 0.1	60.1
	, 5			1 6			c 0.1	₹ 0.3	€ 0.1	<0.1
	23	40.1	¢0.1	<0.1	< 0.1		< 0.1	< 0.1	< 0.1	*0.1
Y-S	en	€0.1	40.1	<0.1	< 0.1	4 0.1	< 0.1	< 0.1	< 0.1	<0.1
i	2	<0.1	40.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
	28	<0.1	<0.1	¢0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
1	-	60.1	¢0.1	40.1	₹ 0.1	4 0,1	< 0.1	< 0.1	< 0.1	<0.1
	2	1.0	1.0	1.0	♦ 0.1	♦ 0.1	< 0.1	< 0.1	< 0.1	*0.1
	28	₹.0°	<0.1	<0.1	₹ 0.3	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
7	•	. 07	1 07	1.05		4.0.1	1.0 >	× 0.1	< 0.1	<0.1
	, 0		1.0	, ¢0.1	4 0.1	< 0,1	< 0.1	< 0.1	< 0.1	<0.3
	28	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
7	•	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	* 0.1	40.1
	91	100	40,1	£0.1	4 0 P	1 0 ¥	4 0.1	4 0.1	< 0.1	40.1
	28	<0.1	*0.1	€0.1	₹ 0.1	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
1	•	0.3	1.9	0.7	12.0	< 0.1	< 0.1	< 0.1	₹ 0.1	<0.1
1	10	0.7	1,3	4.0	4.8	6.0	4.6	8.4	2.4	<0.1
	28	4.0	8.0	0.1	0.2	9.0	3.0	2.2	1.2	<0.1
A-10	•	0,3	0.7	6.0	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
	10	0.3	0.3	1.0	< 0.1	< 0.1	< 0.1	< 0.1	* 0.1	<0.1
	28	0.3	0.8	0.1	1.9	3,1	< 0.1	< 0.1	< 0.1	*0.1
A-111	•	0.1	0.1	<0.1	38.0	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
	01	0.1	4.0	<0.1	26.4	36.0	22.8	13.2	7.8	9.0
	28	0.1	1.03	<0.1	e0 •0	9.2	16.3	13.0	13.1	3.6

1/ Westgate Wastevater Treatment Flant, Alexandria, Virginia.
7/ See table 2 for alloy identification.
3/ Surface beneath teflon spacer.

TABLE 21. EVALUATION SUMMARY - ALLOYS - SITES 1, 2, AND 3

Alloy code	Si:e	of the state of th	Site 1	2/		mance ra Site 2 3	ting 1/		Site 3	11/	A
No.	exposure	3 то	10 mo	22 mo	3 000	10 mo	28 що	3 1110	1.0 шо	28 mo	Average
A-l	Gas	4	4	4	3 2	74	2	2	3	3	3.0
	Interface Liquor	11	3 3	3 3	3	14 14	Ħ Ħ	3 3	3 4	3	3.3 3.3
A-2	Gas Interface	4	4 3	3 3	4	4	3	ц	4	3	3.0
	Liquor	4	3	3	4	4	3	4	3	3	3.3 3.0
A-3	Gas Interface	4	Į,	3	4	4	3	4	Ťì	3	3.0
	Liquor	4	3	3	4	4	4 4	4 Li	3 4	3	3.3 3.3
A-4	Gas Interface	1	1	1	1	1	1	1	1.	1	1.0
	Liquor	1	1	1	1	1	1 1	1	1	1	1.0
A-5	Gas Interface	1	1 1	1	1	1	1	1	1	1	1.0
	Liquer	1	1	1	1	1	1	1	1	1	1.0
A-6	Gas Interface	1	3	3	1	1	1	1	1	1	1.7
	Liquer	1	1	1	1	1	1	1	1	1	1.0
A-7	Gas Interface	1	1	1	1	1	1	1	1	1	1.0
	Liquer .	1	1	1	1.	1	1	1	1	1	1.0
4-8	Gas	1	1	3	1	1	1	1.	1	1	1.7
	Interface Liquer	1	1	1	1	1	1	1	1	1 1	1.0
1-9	Gas Interface	4	4	3	4	4	3	l;	3	3	3.0
	Liquer	3	3 4	3	4	3	3	3 2	3 3	3 3	3.0
-10	Cas Interface	3	3	3	2	2	3	2	2	3	3.0
	Liquor	3 4	3	3	3	3	3	2	3 S	3	2.7
-11	Gas Interface	4 41	4	4	1	4	4	4	ц	4	4.0
	Liquor	Ų	4	4	1 4	3	3 4	2	4 4	Ħ Ħ	3.7 4.0

1/ Assigned as follows in accordance with average corrosion rate (x) and maximum pitting rate (y).

www.yr	rosion rate (x) mils/yr	or	Maximum pit	ting rate (y) mils/yr	Rating
x <3	x<0.1	25	y<3	y<0.1	1
3 < x <25	0.1 <x<1.0< td=""><td></td><td>3≤y< 25</td><td>0.1≤y<1.0</td><td>2</td></x<1.0<>		3≤y< 25	0.1≤y<1.0	2
25 < x <254	1.0 <x<10.0< td=""><td></td><td>≤y< 254</td><td>1.0≤y<10.0</td><td>3</td></x<10.0<>		≤y< 254	1.0≤y<10.0	3
x > 254	x>10.0		y> 254	y>10.0	4

erm ... pris

^{2/} Tapia Water Reclamation Facility, Calabasas, California.

Speedway Kastewater Treatment Plant, Indianapolis, Indiana.

Westgate Katewater Treatment Plant, Alexandria, Virginia.

Average of 22-month rating at site 1 and 28-month ratings at sites 2 and 3.



Figure 16. Sensitized Type 304 stainless steel specimen exposed in the gas zone at site 1 for 22 months. Note pitting due to sensitization.

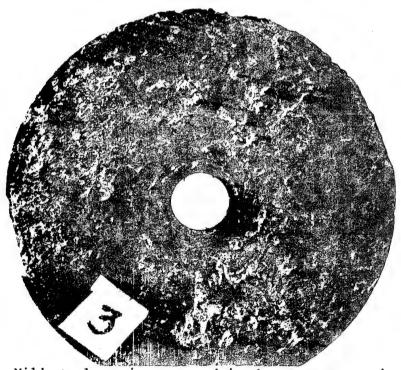


Figure 17. Mild steel specimen exposed in the gas zone at site 2 for 28 months. Surface is deeply pitted.



Figure 18. Low alloy steel specimen exposed in the liquor at site 2 for 28 months. Specimen is perforated.

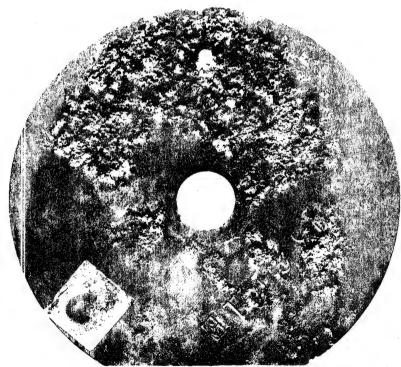


Figure 19. Aluminum alloy 6061 exposed in the gas zone at site 2 for 28 months. Sample is perforated.

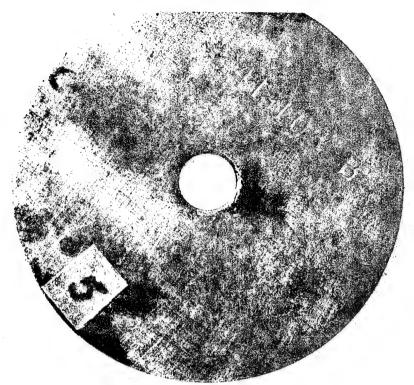


Figure 20. Copper specimen exposed in the gas zone at site 2 for 28 months. Sample is pitted in one localized area only.



Figure 21. Edge view of gray cast iron coupons, unexposed (top) and exposed for 28 months in the gas-liquor interface at site 2. Thickness loss was caused by graphitization.

- (3) Low alloy steel (Alloy A-3)
- (4) Aluminum alloy (Alloy A-11)
- 2. Stressed specimens. Table 22 shows the results of exposure of stressed alloy specimens. The split specimens are shown in figures 22 and 23. All stressed alloys performed satisfactorily in all exposures at the three test sites except:
 - a. Mild steel (Alloy A-2)
 - b. Low alloy steel (Alloy A-3)
 - c. Aluminum alloy (Alloy A-11)

Rubber and Plastics

- 1. Rubber Sheeting. Physical property test results are shown in table 23. The effect of exposure on rubber materials is discussed below by rubber type:
 - a. Generally satisfactory
 - (1) Butyl. Very slight strength loss. Slight shrinkage in one sample. Swelling and moderate strength loss at site 2 liquor/gas interface indicating contact with a petroleum product.
 - (2) Chlorosulfonated polyethylene. Slight strength and elongation loss accompanied by slight hardening in all gaseous phases.
 - (3) Ethylene propylene diene monomer. Spotty swelling with resulting moderate change in physical properties in the splash zone indicating some petroleum contact.
 - (4) Polyacrylate. General moderate strength loss.
 - b. Satisfactory for limited use
 - (1) Natural. Strength loss, softening, distortion, swelling from petroleum contact, initial ozone cracking, and indications of micro-organism attack. Use should be limited to applications in which high strength, high resiliency and resistance to fatigue, crack growth and tearing are essential, and exposure to oxygenated, bacteria-laden water, is minimal.
 - (2) Nitrile-butadiene. General strength loss with slight elongation loss. Initial ozone cracking. Should not be used under conditions of combined stress and atmospheric or ozone exposure.
 - (3) Silicone. Severe mechanical damage, caused by suspended solids and debris, observed in the splash zone. Discoloration of one product (R-32) accompanied by loss of strength and elongation loss. Should be formulated for bacteria resistance and limited to uses not subject to severe abrasive conditions.

TABLE 22. TEST RESULTS - STRESSED METALS - SITES 1, 2, AND 3*

			Exposure		
Code No.	Alloy** Identification	Site No.	Phase	Period (months)	Test results
7	Mild carbon steel, AISI 1020	2***	Liquor	28	Both specimens completely fractured
		3#	Interface	10	One specimen split; wearing indicative of abrasion
		3#	Interface	20	Both specimens split
ю ·	Low alloy steel, USS Cor-Ten	E	Interface	28	One specimen split
11	Aluminum alloy, AA-6061	2	Liquor	10	One specimen split
			Liquor	20	Both specimends split; wearing indicative of abrasion

alloy No. 1, gray cast iron, and alloy No. 9, austenitic gray cast iron, are not subject Since Only those materials which split during the course of the exposure are listed. to this test, only nine alloys were exposed.

** See table 2 for alloy identification.

*** Site 2 - Speedway Wastewater Treatment Plant, Indianapolis, Indiana. # Site 3 - Westgate Wastewater Treatment Plant, Alexandria, Virginia.

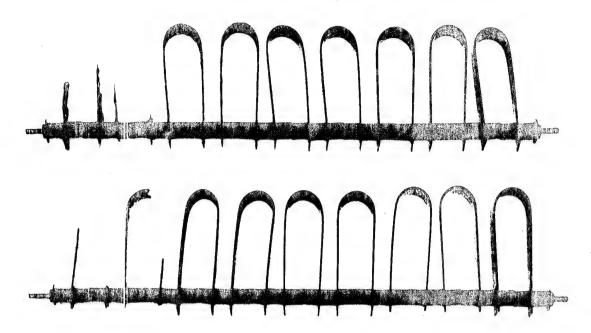


Figure 22. - Duplicate mild steel (top left) and aluminum alloy 6061 (bottom left) stressed specimens failed after 28 months' exposure in the liquor at site 2.

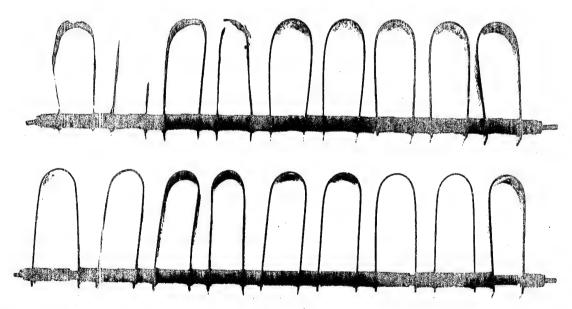


Figure 23. - Duplicate mild steel (first two samples, top row) and low alloy steel (second two samples, top row) stressed specimens failed after 28 months' exposure at the interface at site 3.

TABLE 23a. TEST RESULTS - RUBBER SHEETING - MATERIALS R-29, R-17, R-5 (metric units)

State Stat	Strate S	Property Exposure Steel Property Exposure E		181 100			Butyl - C			Butyl - C	•		Neoprene	
Special Colored Step 2/2 St	Spourse Site 1/ Site 1/ Spourse Spou	Section Site 1		Exposure		Cas	Interface	- Course						
10 10 10 10 10 10 10 10	1	1	roperty	Exposure time, months					2	INCELIACE	Liquor	80 80 80	Interface	Liquor
3 2 111.2 111.2 111.3 111.	3 2 11.2 11.2 11.3 11.3 10.1 10.4 9.9 16.5 16.9 3 2 11.2 11.2 11.2 11.3 10.1 10.1 10.1 10.1 10.1 11.5 11.5 3 2 11.2 11.2 11.2 11.3 11.3 11.3 11.5 3 2 11.2 11.2 11.2 11.3 11.3 11.5 4 5 5 5 5 5 5 5 5 5	3 2 13.3 14.5 14.3 10.1 10.4 9.9 16.5		0		• • •								
3 2 113 114 115 11	3 2 113 113 114 11	3 2 13 14 2 15 3 4 2 15 3 4 2 15 3 4 2 15 3 4 2 4 4 4 4 4 4 4 4				O H	1 1 1	,	10.1			16.5		
10 10 10 10 10 10 10 10	28 1 13 1 13 1 13 1 15 1 15 1 15 1 15 1 1	10 10 10 10 10 10 10 10	•	~	2	13.3	7 7 7	5.4.5	10.1	10.4	6.6	16.5	16.9	17.1
9 2 1 11.6 11.2 11.3 11.5 9.1 10.9 11.0 11.0 11.7 11.3 11.5 11.5 11.5 11.5 11.5 11.5 11.5	19	19			~	? =	74.5	13.9	1.6	9.0	9.1	15.1	15.5	15.
10	9 2 117.5 13.9 14.5 9.6 14.8 16.2 15.9 14.5 9.6 14.2 15.9 14.8 14.8 14.8 15.9 14.2 15.9 15.9 15.9 15.9 15.9 15.9 15.9 15.9	10 10 10 10 10 10 10 10					13.0	7.1.7	3.5	9.6	9.7	13.5	14.7	14.6
28 1 1 1 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	26 2 112.3 114.9 9.6 9.1 9.6 16.2 15.3 11.0 11.0 11.1 11.0 11.2 12.0 12.0 14.1 9.6 9.6 9.6 16.2 15.3 11.0 11.1 11.0 11.2 12.0 9.4 9.6 9.6 16.2 15.3 11.0 11.1 11.0 11.0 11.1 11.0 11.0 11	1		•	•	2 -	5.0.7	13.0	7.5	10.7	9.5	14.8	16.2	16.0
28	26 2 113.2 13.2 13.3 9.4 9.5 9.8 14.2 12.9 13.3 9.4 9.5 9.8 14.2 12.9 13.3 9.4 9.7 9.8 14.2 13.3 9.4 9.4 9.7 9.8 14.2 13.3 9.4 9.7 9.8 14.2 13.3 9.4 9.4 9.7 9.8 14.2 13.3 9.4 9.4 9.7 9.8 14.2 13.3 9.4 9.7 9.8 14.2 13.3 9.4 9.7 9.8 14.2 13.3 9.4 9.7 9.7 9.8 14.2 13.3 9.4 9.7 9.7 9.8 14.2 13.3 9.4 9.7 9.7 9.8 14.2 13.3 9.4 9.7 9.7 9.8 14.2 13.3 9.4 9.7 9.7 9.8 14.2 13.3 9.4 9.7 9.7 9.9 14.2 13.3 9.4 9.7 9.7 9.9 14.2 13.3 9.4 9.7 9.7 9.9 14.2 13.3 9.7 9.7 9.7 9.0 9.2 10.0 11.7 9.7 9.0 9.2 1.0 9.0 9.2 1.0 9.0 9.2 1.0 9.0 9.2 1.0 9.0 9.2 1.0 9.0 9.2 1.0 9.0 9.2 1.0 9.0 9.2 1.0 9.0 9.2 1.0 9.0 9.2 1.0 9.0 9.2 1.0 9.0 9.2 1.0 9.0 9.2 1.0 9.0 9.2 1.0 9.0 9.2 1.0 9.0 9.2 1.0 9.0 9.2 1.0 9.0 9.2 1.0 9.2 1.0 9.0 9.2 1.0 9.0 9.2 1.0 9.0 9.2 1.0 9.0 9.2 1.0 9.0 9.2 1.0 9.0 9.2 1.0 9.0 9.2 1.0 9.0 9.2 1.0 9.0 9.2 1.0 9.0 9.2 1.0 9.0 9.0 9.0 9.0 9.0 9.0 9.0 9.0 9.0 9	28 1 12 12 13 13 13 14 8 1 8 1 8 1 8 1 12 13 13 13 14 8 1 8 1 8 1 8 1 8 1 8 1 8 1 8 1 8 1		•	. ~	7.5	13.3	14.5	9.6	9.1	9.6	16.2	15.3	
26 2 11.2 13.2 13.3 9.4 9.7 9.8 12.7 13.3 6 1 11.6 12.2 13.4 8.1 8.1 8.6 9.8 12.7 13.8 13.8 11.6 12.2 13.4 8.1 8.1 8.6 9.5 13.0 13.8 13.8 13.8 13.8 13.8 13.8 13.8 13.8	28 2 11.2 13.2 13.3 9.4 9.7 9.8 12.7 13.8 13.9 14.8 13.1 9.4 9.7 9.8 11.2 13.1 9.4 9.7 9.8 9.8 9.8 12.7 13.8 13.8 13.8 13.8 13.8 13.8 13.8 13.8	28 2 147.2 13.2 9.4 9.6 9.8 12.7 13.1 29.4 9.6 9.8 12.7 13.1 29.4 9.6 9.8 12.7 13.1 29.4 9.6 9.8 12.7 13.1 29.4 9.7 9.8 11.8 12.7 13.1 29.4 9.7 9.8 11.8 12.7 13.1 29.4 9.7 9.8 11.9 13.1 29.5 11.6 12.7 13.1 29.7 6.0 6.9 6.5 6.0 13.0 13.0 13.0 13.0 13.0 13.0 13.0 13				12:	12.8	14.8	9.5	8.8	8.6	14.2	12.0	
14.6 17.2 13.12 9.4 9.7 9.3 13.10 1	14.6 7.2 114.7 9.4 9.7 9.3 114.9 11.8 15.6 11.6 12.2 114.1 8.1 8.6 9.9 11.0 11.7 15.6 15.6 15.6 15.6 15.6 15.6 15.6 15.6 15.6 15.6	14.6 17.2 13.1 9.4 9.7 9.3 11.6 13.8 3		80	٠,٠	14.0	13.2	13.3	4.6	9.6	8.6	127	13.1	
1, 8, 1, 8	0	11.6 12.2 14.1 8.1 8.6 9.5 11.0 11.7 1		3	v (14.2	7.2	13.2	4.6	9.7		0 4	10.0	
10 10 10 10 10 10 10 10	0	0			ກ.	11.8	12.2	14.4	8.1	· ·			9	5
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1. Tanta Utton B.1	1: Tapia Water Reclamation Plant, Calabasas, California	1: Tapla Water Reclamation Plant, Calabasas, California 2: Speedvay Waterwater Treatment Plant, Indianapolis, Indiana 3: Westate Watervater Treatment Plant, Indianapolis, Indiana			. ~	,,	2.0	0.0	0.4-	7.2	-1.6	-1.3	1.7	0
1: Fants Union Best1.2	1: Tapia Water Reclamation Plant, Calabasas, California	1: Tapia Water Reclamation Plant, Calabasas, California 2: Specdusy Wastewater Treatment Plant, Indianapolis, Indiana 3: Westaate Wastewater Treatment Plant, Indianapolis, Indiana	_		1 4	1.5	0.0	9.0	-1:1	-1.3	-1.9	0.5	-	
Farts Union Belleville	1: Tapia Water Reclamation Plant, Calabasas, California	1: Tapia Water Reclamation Plant, Calabasas, California 2: Speedway Wastewater Treatment Plant, Indianapolis, Indiana 3: Westgate Wastewater Treatment Plant				•	•	-0.1			-1.2			
			te 1:	1 :										;

TABLE 23a. TEST RESULTS - RUBBER SHEETING - MATERIALS R-29, R-17, R-5 (English units)

dill.

Exposure Sire 1/4		Katerial			Buryl.			B. 0.17	٠		B-3	
Separatre Size 1/4		Exposure		8	Interface	Liquor	1 8	Interface		+	Interface	1
28 1.75 2.13C 2.13C 1.47D 1.72D 1.72D 1.72D 1.72D 2.45D 2.45	Property	Exposure time, months			TO MANAGEMENT STATES					h-da si Quiquiga ironga		
1,000 1,00	,	0	ಶ	2,160			1,479			2,400		
2 1,940 2,065 2,030 1,310 1,220 1,320 2,36	3¢j	-	p-6 (20175	2,120	2,080	12,470	2,515	1.450	7,430	7.450	7 A 20 E.
28 1.725 1.130 1.940 1.1310 1.1400 1.1400 1.1400 1.1400 2.14000 2.14000 2.14000 2.14000 2.14000 2.14000 2.14000 2.14000 2.14000 2.14000 2.14000 2.14000 2.14000 2.14000 2.14000 2.14000	101	7)	no r	7,960	2,065	2,030	1,320	1,260	1,330	2,200	2,260	2,260
28 1.72 1.72 1.70 1.70 1.70 1.70 1.70 1.70 1.70 1.70	-			21010	2000	2,000	1,340	1,260	1,420	1,960	2,140	2,160
28 1 1.000 1		3	4 6	21.6	2,020	2.010	1,330	1,565	1,390	2,155	2,360	2,325
28 1 1,865 1,915 1,940 1,375 1,435 1,435 1,435 1,900 1,700 1,375 1,435 1			1 en	2.000	1.870	2 090	7.00	1,326	1,405	2,360	2,220	2,280
28 2 2,000 1,005 1,900 1,130 1,415 1,435 1,435 1,100 1,100 1,100 1,125 1,135 1	3 1 2		rel	1 RKS	1 915	0,0	1 375	1, 203	1,430	2,065	1,880	2,065
1,725 1,775 1,770 1,130 1,135 1,135 2,175 2,1015 2	92	28	•	2,070	1 055	000	1,010		C C & T	C 90 4 7	7,500	2,033
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28 2 590 340 610 350 340 345 275 240 0 4 66 63 30 610 350 340 345 270 240 1 525 530 660 320 340 345 270 240 2 5 5 5 6 6 6 6 6 6 6 6 72 70 240 2 5 6 6 6 72 71 72 71 72 71 72 71 72 71 72 71 72 72 72 72 72 72 72 72 72 72 72 72 72				3	240	000		340	350	270	235	250
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28 2 64 64 64 64 65 72 72 72 72 72 72 72 72 72 72 72 72 72		}		508	9 5	019	2 5	340	385	270	240	240
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28	/ ₁₁		3	56	63	63	63	/ P	3 3	100	8 6	2 6
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26 1 0.3 1.0 0.2 -1.2 -1.7 -0.9 -1.1 -1.5 -1.5 -1.5 -1.5 -1.5 -1.5 -1.5			· m	0.5	1	1	2.7.0	4.0	7.1	0.0	2.4	5. B
28 2 0.3 9.9 0.8 -4.0 7.2 -1.6 -1.3 1.7 -0.6 -0.8 -1.1 -1.3 -1.9 0.2 -1.4			-	0.3		0.0	7.7-	20.3	6:1-	-1.0	-0.2	2.2
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31 Site 1: Tapia Water Reclamation Plant, Calabasas, California Site 2: Speedway Wastewater Treatment Plant, Indianapolis, Indiana Site 3: Westgate Wastewater Treatment Plant, Alexandria, Virginia Site 4: USBR Laboratories, Denver, Colorado

TABLE 23b. TEST RESULTS - RUBBER SHEETING - MATERIALS R-30, R-8, R-32 (metric units)

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Second Changes Second	State Stat	10 10 10 10 10 10 10 10	90	m	~	9.9	6.3	10.3	10.2	11.1	2		o ve	ň
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28 1 10.8 11.9 11.5 11.5 11.5 11.5 11.5 11.5 11.5	10.6 11.4 11.5 11.5 11.5 12.0 5.5 4.7 11.0 11.4 10.5 11.6 11.9 11.9 11.0 11.4 10.5 11.6 11.9 11.0 11.4 10.5 11.5 11.5 11.0 11.4 10.5 11.5 11.0 11.4 10.5 11.5 11.0 11.4 10.5 11.0 11.4 10.5 11.0 11.4 10.5 11.0 11.4 10.5 11.0 11.4 10.5 11.0 11.4 10.5 11.0 11.4 10.5 11.0 11.4 10.5 11.0 11.4 10.5 11.0 11.4 10.5 11.0 11.4 10.5 11.0 11.4 10.5 11.0 11.4 10.5 11.0 11.4 10.5 11.0 11.4 10.5 11.0 11.4 10.5 11.0 11.4 11.5 11.0 11.5	Towns		•	2	10.9	11.7	10.9	11.16	10.8	11.6	0	, L	rur
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3 3.0 1.6 -0.4 0.6 3.2 0.2 -0.8 -0.8 -0.8 -0.8	Site 1: Tapia Water Reclamation Plant, Calabasas, California	Site 1: Speedway Wastewater Treatment Plant, Indianapolis, Indiana		28	• •	200	. «	9 4	7.	, ·	22.0	6.0	0.0	0
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	Site 1: Tapia Wat	Site 1: Tapia Wat Site 2: Speedway				•	•	9		•	- o	•	,	o o

TEST RESULTS - RUBBER SHEETING - MATERIALS R-30, R-8, R-32 TABLE 23b.

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Property	Exposure time, months	Site $\underline{1}$ /									
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us		е	1,330	1,520	1.580	1.520	1.590	1.610	750	084	620
		-	1.465	1.665	1.465	1.630	1.705	1.635	1 000	860	5779
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3 A G 9			630	685	630	450	420	420	155	150	105
	•	7	980	605	620	8	385	425	140	140	120
			550	505	545	415	410	435	95	150	120
	•		615	575	240	077	430	400	135	140	80
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ď		m	3.0	1.6	4.0-	9.0	3.2	0.5	-0.6	90	1.8.
	_	7	,	1	-0.8	+	,	7.0-		. !	0

Site 1: Tapia Water Reclamation Plant, Calabasas, California
 Site 2: Speedway Wastewater Treatment Plant, Indianapolis, Indiana
 Site 3: Westgate Wastewater Treatment Plant, Alexandria, Virginia
 Site 4: USBR Laboratories, Denver, Colorado

TEST RESULTS - RUBBER SHEETING - MATERIALS R-532, R-25, R-34 (metric units) TABLE 23c.

	Material			R-532 Siltcone - G			R-25 Natural			R-34 NAR	
Property	Exposure	6140 17	Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	1 founds
	time, months	orre T/									ontar
	0	=	7.5			16.8			3		
ų a 8	•				-	11.4	13.3	15 6	23.0	200	
Buə.	۵.	2 m		7.4	5.2	10.5	13.8	13.3	17.5	17.8	10.0
175			2.5	2.0	5.9	11.1	10.3	10.9	15.9	16.4	16.
ATP.	6	8	6.5	17.9	8.9	10.8	13.9	13.3	16.7	18.4	19.
ī‡∎		m	5.7	5.0	6.8	11.2	10.3	11.1	17.1	17.9	18.
uə;	28	1 0	1 4	1 4		1.8	9.7	10.6	12.3	13.1	10.
		m	3.6		0 0	0.5	2.9	8.1	16.2	16.3	16.
+		77	1		7.2		1.1	8.5	14.8	15.8	15.3
	0	4	570			615					
	r	٦,	١,	•		610	625	650	515	003	
3	n	7 6	565	620	595	900	510	610	465	160	200
uəc			430	495	430	620	590	580	430	430	430
	6	2	480	505	520	560	019	615	420	480	530
		3	420	400	530	250	505	575	5 17 2	445	011
		-	,			270	Uth	505	405	400	400
	02	2 1	515	480	094	545	390	555	200	300	385
		n #	280	340	450	450	530	260	315	370	330
					235	•		540	1	•	385
	0	77	52			64			99		
	~	٦ ,	1 (1 (64	50	52	99	99	64
, V		, m	6 2	20	52	25	50	80 #	68	29	68
ə:		1			1	52	49	20	71	99	67
тоц	55	۰ دی	53	51	54	25	20	8,8	0 %	00 V	67
S		7	56	52	53	52	50	51	89	67	99
	28	. ~	l a	1 = 1	' =	51	50	50	19	99	67
-	•	۳,	56	54	2 2	5 ر	T (25	67	99	29
		7			56	; '	; •	50	-	1 00	68
-				ı	,	0.0	1.4	0.8	0		
38 1	•	v m	0.1	2.9	8.1	-2.4	6.5	6.0	-1.8	-6.0	1.6
184: 88:		1		1:1	7.5	2.0	0.5	2.8	0.0	-0.2	7.0
	σ,	2	0.3	2.9	1.6	, o	2.0	2.6	9.0	e .	4.0-
ins:		m -	0.3	1.0	9.0	-0.8	1.3	0.0	-0.7	* ° °	0 0
	28	1 2	10,1	0	1 -	-2.0	0.0	-1.0	0.2	-0.2	-0.3
ď		3	, ri	. 60	L. C	1.1.	ر. ده	6.0	7-0-	9.0	-0.1
		7	1		2.3		1.0	0.1	7.0-	7.0	0.1
					,				,	,	7. T

TABLE 23c. TEST RESULTS - RUBBER SHEETING - MATERIALS R-532, R-25, R-34

	96-12 96-12	or Gas Interface Liquor		1 116	1,050	2,540 2,590	2,310 2,380	2,435 2,670	1 2,530 2,605 3,690	1.795 1.905	2,350 2,370	2,160 2,295		er er	540 620	465 460	430 430	420 480	144 144 144 144 144 144 144 144 144 144	405 400	335 360	316 320	g .		99	000	71 56	66 66	39 T	60 00 V	(b) (c) (c) (c) (c) (c) (c) (c) (c) (c) (c	67 68	60	7.0	-1.9 -6.0 1.9	0.0 -0.2	-0.6 -0.3	-0.2 0.4	-0.7	-0.4	4.0-	7
units)	E-25 Sacurol	Gas Interface Liquor		2.450	O'LO' I	2,010	1,500	2,020	1,630 1,500 1,620	1,420	50	1,030	1	615	625	510	590	610	560 505 575	0//	940	230			5	R G	6.9	69	52 50 60	50	44	~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~		****	-2.4 6.5 0.9	0.2	0.2	4 r	200			
(English units)	R-532 Silicone - G	Gas Interface Liquor		1,100		945 I. GEO 1,105	910 865	25.00	835 730 995		_	685 915	1,055	570	. :	565 620 595	695	, 5	420 400 530		515 480 460	340		23		32	ž	1 5	56 52 54		Z	34		9	89	1.7 5.2		0.3 1.0 0.6		1.3	1.8 2.1	
	Material	Exposure	Exposure Sire 1/	0	7 × 0	71	7-				76	~	9	9	rd (•		I	28	m	9	0		M	6		, ,		25	F) V	3		e4 e			4 m		28 2	m ·	-
			Property	Ę.	:)5:		828 FE		i i	wo	J								of:	I								n pa		Phone Die		reser			D)			o a			ď	

1/ Site 1: Tapia Water Reclamation Plant, Calabasas, California Site 2: Speedway Wastewater Treatment Plant, Indianapolis, Indiana Site 3: Westgate Wastewater Treatment Plant, Alexandria, Virginia Site 4: USBR Laboratories, Denver, Colorado

TABLE 23d. TEST RESULTS - RUBBER SHEETING - MATERIALS R-27, R-18, R-31 (metric units)

Topia digenstrin fenatic Strength operity for the strength operity for the strength operity of the strength operity op	Site 1/ 1 2 3 3 2 1 2 2 2 2 2 2 2 3					CSPB			KPDM/Butyle	
rcent hPa		90	Interface	Liquor	Gas	Interface	Liquor	Can	Interface	Liquor
rcent MPa	2 2 2 2 2 3	13.9			10.4			0.0		
rcent MPa	2 8 4 2	14.8	7.5	12.2	9.1	10.7	10.4	0.0	6.0	
rcent MPa	1 2	w.c	12.2	11.6	æ .	9.3	9.5	0.8	0.8	1.0
ceur HB	7	9.1	6.7	13.0	7.6	20.0	11.1	1.0	0.8	0
rcent		11.9	8.1	0 00	, 0	11 3	1. C	5.0	1.0	٠,
rcent	3	8.9	12.3	8 3	8.4	12.3	10.1	200	0.0	٦ ٥
rcent	~ ·	9.01	11.6	12.3	9.4	11.2	11.9		2.1	
rcent	2 0	10.7	10.0	7.5	9.6	10.0	10.0	0.0	80,0	• -
rcent	n ar	13.0	ه. ت	14.0	7.1	10.0	11.9	1.0	1.1	0,
rcent										1
rcent	7	125			465			200		
rcent	٠, د	135	95	110	475	170	Oth	215	245	245
rcent	4 6	105	551	120	100	400	410	200	210	250
rcen		a de	200	100	455	425	450	235	240	230
	٠ ٢	130	011	105	350	340	400	235	565	260
	6	06	110	110	335	390	370	280	265	220
d	1	95	110	100	330	355	370	230	235	243
28	2	120	120	100	380	460	430	190	230	250
	m:	130	80	120	290	00#	410	250	260	260
	7			110		•	310	1	, 1	235
0	7	7.7			68					
	-	70	71	10	89	KK	17		1	1
e a	~	72	72	72	69	89	800		ı	•
.,v.	3	29	7.1	11	67	99	67	1 1		• 1
, =		17.	72	72	74	69	68			
210	N ÷	72	72	73	70	68	68	,		•
	7	1,2	0/	7.	72	89	67	1	1	•
	4 0	71	7 5	7 :	71	70	69	•		'
}	, ,,	15	0 4	1,	7.2	29	89	,		,
	1 =	<u>.</u> 1	3 '	200	2 1	2/	200	1	,	•
							63		•	1
	(1.9	2.1	1.3	0.0	1.5	1.6	5.0	-18.2	-20.
n ə	v "	ν. c.	# C	0.0	9.0	1.3	1.5	-1.7	-8.0	-1.5
		6.4.0	7.7-	-3.5	0.7	0.5	3.1	9.9-	-16.2	-12.
	(V)	, e) e:) c	N (1	2.0	-5.7	-13.5	-14
, ;	3.	-2.7	-3.0	0.0	, O.		3.6	20.00	29.0	1.5
ri ceu		0.5	1.1	1.1	-0.1	-0.1	-1.0	-0.7	-1.9	4
15	7 (E . C	-1.6	-2.3	# 0-	2.5	0.5	-11.4	-31.7	-24
ď	n =	-3.5	-1.1	2,5	-1.6	7.0-	-0.1	-28.7	-32.2	-31.
	,		ı	-0.4	1	1	13.4	•	1	0
Site 1: Tapiu Water Re	clamation Pl	ant, Calab	ater Reclamation Plant, Calabasas, California	nia						

TABLE 23d. TEST RESULTS - RUBBER SHEETING - MATERIALS R-27, R-18, R-31 (English units)

	Material		Ž	E-27 Polyacrylate	6		32.50			EPDH/Bucy1*	
	Exposure		Cas I	Interface Liquor	Liquor	Gas I	Interface	Liquor	Sec. 1	Interface Liquor	Liquor
Property	Exposure time, months	Site <u>1</u> /									
	C	41	2.030			1.520			143		
			2,150	1,090	1,770	1,315	1,565	1,523	136	130	9
Su	m	2	1,350	1,776	1,690	1,280	1,530	1,540	5 5	120	145
		7	1,020	1,070	1,050	1 215	1 755	1.520	140	155	155
	•	40	1,320	175	2002	1,335	1,645	1.635	140	130	150
/91	n	7 -	1 20%	1.790	1.210	1.230	1,785	1,465	120	155	140
		1	1.540	1,635	1,790	1,375	1,625	1,740	160	180	165
no	28	7	1,565	1,460	1,085	1,395	1,445	1,460	140	120	797
7		m ·	1,890	1,000	2.040	1,040	1,455	1,750	ĝ,	2 +	3
		4	•	•	1,335						
		4	125			465			200		
			135	95	110	475	670	077	21.5	245	243
,	m	7	105	33	120	094	9	017	8 8	210	2 2
		3	105	100	160	455	425	200	255	376	265
		1	8	20	110	350	2 6	3 5	7 6	592	220
ng ug	•	~ .	<u>۾</u>	011	6 5	2 5	2 4	007	202	230	243
		1	2	110	200	330	355	370	230	235	260
	•	4 6	2 5	120	200	38	460	430	81	230	250
	3	, n	130	8	120	290	004	410	22	260	3 2
		4	,	-	110	•	•	310	·		3
	c		7,6			89			٠	•	١
		-	2	71	20	89	8	49		•	•
	•	- 7	22	72	77	69	83	99	,	•	٠
.,V		m	29	11	71	19	99	67			1
, i		1	74	72	72	74	69	89	•		•
910 191	•	7	72	72	73	2	9	9	,	•	• (
ųs ep		-	77	0/	1/	7,7	8	3			
		-1	72	72	11	7,	25	P 6			
	28	7	77	20	7,	7/	000	9 0		1 1	•
		m ·	7.7	80	10 e	?	21	9 e9) 0	9
		8	,	•	7/			5			
		_	-	2.1	1.3	0.0	1.5	1.6	5.0	-18.2	-20.6
υž	•	• •	1	4.4-	-3.0	-0.6	1.3	1.5	-1.7	-8.0	-1.5
	•	4 6	-	-2.2	-3.2	0.7	0.2	3.1	9.9-	-16.2	-12.0
		-	0.0	4.0	1.6	0.0	1.2	0.7	-5.7	-13.5	-14.9
tra Tra	6	7	0.3	0.2	0.8	0.5	2.3	3.2	0.6	0.8	-1.0
		n	-2.7	-3.0	0.8	-0.8	0.3		-10.0	-31.0	
u L		-1	0.5	1.1	7.7	-0.1	- ·	0.10		-1.9	26.45
đ	82	7	-1.6	-1.6	-2.3	4.4	7.0	9	128.7	-12.2	-31.2
		m	-3.2	-1.1	-2.5	0.7-	*	13.4			0
		4	•		-0.4	•	-	17. ct			

2. Plastic sheeting. - These materials had generally satisfactory performance.

The chlorinated polyethylene exhibited initial swelling which stabilized during wet exposure and decreased when dried.

The initial stiffening of the polyvinyl chloride sheeting has continued throughout the exposure period. Elongation losses generally have been accompanied by strength increases, indicating loss of plasticizer rather than attack on the polymer. Limited thermo-gravimetric and infrared analysis also indicated plasticizer loss correlating with increased stiffness.

The chlorosulfonated polyethylene has shown continued stiffening. Minimum change in the control (Denver tap water) specimens indicates possible micro-organism attack.

Physical property test results are shown in table 24.

3. Fabric reinforced sheeting. - These materials had generally satisfactory performance.

No significant change occurred in the butyl. The ethylene propylene diene monomer materials had slightly lower wet strength. The chlorinated polyethylene materials have considerable swelling and slightly lower wet strength. One chlorinated polyethylene sample was severely abraded at the interface zone of the Westgate site. The chlorosulfonated polyethylene showed some increase in stiffness and moderate swelling. Physical property test results are shown in table 25.

4. Rigid polymers. - No significant change from the rather wide range of original test results has occurred.

No change was observed in the high-density polyethylene pipe specimens during visual examinations at the test sites and at the end of the exposure period. Hoop stiffness tests at the end of the exposure period also indicated no change in the physical properties.

Physical property test results for the rigid polymers are shown in table 26.

Protective Coatings

The results of protective coatings applied to steel surfaces are shown in tables 27 through 32. Tables 27, 28, and 29 show the results of coatings exposed on steel and tables 30, 31, and 32 exhibit the results of coatings applied to concrete. Typical defective and defect-free coated panels are shown in figures 24 and 30. The evaluation summary of coatings performance is shown in tables 33 and 34.

The coatings are rated as follows according to their overall performance in all three zones at the sites at which the coatings were exposed:

TABLE 24a. TEST RESULTS - PLASTIC SHEETING (metric units)

	Matorial			B-6415 PVC		pr - quantum-ma	E-6273 CSPE			8-6475 CPE	
	Exposure		883	Interiace	Liguor	Cen	Interface	Liguor	Çez	Interface	5000
Property	Exposure time, months	81to 1/									
	0	158	21.5			12.5			14.7		
ų		7	18.6	21.9	21.6	12.4	14.5	13.5	13.9	14.8	13.3
181	1 ~1	C)	15.6	•	19.5	10.9	13.4	18,4	12.8	12.3	\$100 m
uo.		r-n	21.4	20.8	21.2	13.7	15.7	16.3	13.6	13.5	(e-4
		-1	22.7	24.9	23.7	18.2	15.8	14.6	14.3	14.3	14.0
Dags	Ø.	6.	21.9	19.5	18.7	14.6	18.0	15.1	12.8	11.3	13.5
		κv	20.7	20.5	21.0	18.3	17.7	17.4	6.6	9.00	(2) (1)
ter			22.2	21.4	22.2	14.1	17.3	16.8	13.2	14.5	14.0
19]	26	63	21.4	27.2	17.7	16.0	19.2	17.8	13.6	11.2	and and
i.	-	"	21.2	18.6	20.4	20.4	21.0	22.0	11.6	12.8	13.5
		B	,	•	22.0	ı		14.8	,	•	13.5
	c		300			3.6			365		
	,		300	355	000	515	210	.,,	300		
	•	٠, ١	202	330	230	250	542	502	340	330	310
° ti	^	۰ ۰	320	1 000	336	200	102	200	320	000	2 6
		•					210	037	200	200	663
10:	•	٠,٠	233	292	270	555	215	245	280	295	300
	>	٠,٠	200	250	200	261	200	00.5	200	212	0 8 6
		1	25.5	200	200	200	130	0.7	300	200	202
(3	ę	٠,٠	622	577		25	57	183	225	276	275
	8	٠,	250	٠;	250	001	41	150	8	S	in a contract of the contract
		m a	\$25	210	082	125	128	132	ŝ	278	
					637			24.2			202
		~	3.0	0.0	0.4-	6	2.1	1.7	9	11.8	-
	•	~		-	-	3		3	-	(e	2
98	•		15	0.17	-2.0	-	. u.	4	1	1 13	7.1
			-5.0	-6.1	-6.6	5.	27	2.6	17	10.5	8 8
	6	0.	9.0	-1.0	0,19	ev.	7.0	2	12	(A)	8.0
	,	m	0	-1.0	0	100	E	2.5		7	7.00
: 32 > J. L		1	-3.0	4.7	-4.3	1.0	2.1	2.0	7.2	7.2	9
	82	~	-7.2	-5.8	-1.5	9.0	0.3	1.8	9.0-	3.5	1.1
d			-1.3	-3.0	9	1.0	1.7	1.8	-1.3	0	4.0-
		#	•	•	-5.3	1	•	2.1	1	•	6.9

1/ Site i: Tapia Water Reclamation Plant, Calabasas, California Site 2: Speedway Wastewater Treatment Plant, Indianapolis, Indiana. Site 3: Westgate Wastewater Treatment Plant, Alexandria, Virginia. Site %: USBR Laboratories, Denver, Colorado.

TABLE 24b. TEST RESULTS - PLASTIC SHEETING (English units)

	Marerial			B-6414 PVC			B-6273 CSPE			B-6475 CPE	
	Exposure		Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	Linner
Property	Exposure time, months	Site 1/						1			ł
	0	4	3,130			1.820			1 990		
цұ\$	r	,,	2,700	3,185	3,140	1,800	2,110	1,950	2,020	2,160	1,94
Buə.	n	3 6	3,110	3.030	3,075	2,000	1,955	2,090	7,010	1,762	2,145
s 18 gus		-1	3,300	3,620	3,440	2,070	2,295	2,160	2,085	2,080	2,04
/q =	6	2	3,180	2,840	2,715	2,125	2,620	2,195	1,870	1,720	1,960
I i		3	3,005	2,930	3,050	2,655	2,575	2,525	1,445	1,305	1,93
811		-	3,224	3,110	3,222	2,058	2,510	2,442	1,923	2,046	2,04
϶I	28	2	3,116	3,949	2,568	2,328	2,798	2,592	1,982	1,630	1,709
		m	3,075	2,704	2,960	2,964	3,050	3,202	1,686	1,804	1,96
		7	,	į	3,203	,	1	2,154	ı	1	1,961
	0	7	300			215			300		
			265	330	240	230	24.5	265	3,40	330	15
4,	m	2	220	1	270	260	185	220	350	265	1 6
ac Tot		3	270	250	325	205	210	220	320	300	295
		7	235	285	270	225	215	245	280	295	30
18	6	7	230	220	170	190	180	200	270	215	29
		3	240	255	290	155	190	140	300	260	26
7		1	255	225	247	202	149	183	225	276	31
	28	2	240	S	170	160	115	150	308	255	241
		9	225	210	280	125	128	132	255	278	305
		7		•	295	'	•	242	,	1	305
		7	3.0	0.0	0.4-	1.5	2.1	1.7	6.2	11.8	7
•	6	7	-1.4	-1.9	-1.4	-2.5	-1.8	6-4-	4.1	4.3	2.6
80		3	-3.5	-1.0	-2.0	1.1	4.5	4.5	7.8	4.5	11
րգլ 88		1	-5.0	-6.1	-6.5	1.5	4.4	2.6	4.8	10.5	3.6
	5	2	-3.9	-1.0	-1.0	3.5	7.0	4.2	5.3	14.2	9
		3	0	-1.0	0	2.4	1.8	2.3	3.0	4.1	ς.
ә э ;ц ,			-3.0	4.7	-4.3	1.0	2.1	2.0	7.2	7.2	-0.3
	87	7	-1.2	-5.8	-1.5	9.0-	0.4	1.8	-0.6	3.5	7
đ		η.	-1.3	-3.0	0	1.0	1.7	1.8	-1.3	0	-0.4
		7	•	1	ر ب						,

1/ Site i: Tapia Water Reciamation Plant, Calabasas, California Site 2: Speedway Wastewater Treatment Plant, Indianapolis, Indiana Site 3: Westgate Wastewater Treatment Plant, Alexandria, Virginia Site 4: USBR Laboratories, Denver, Colorado

TABLE 25a. TEST RESULTS - FABRIC - REINFORCED FLEXIBLE SHEETING (metric units)

	Material		Ē	B-6464 Butyl Mylon reinforced	peouc	**	B-6399 EPDM Mylon reinforaed	pega	16.9.1	B-6467 CPE Wylon reinforoed	p e o	Polye	B-6468 CPE Polyester reinforced	peoroju	14	B-6386 CSPE Bylon reinforced	90
	Exposure		Gas	Interface Liquor	Liquor	883	Interface	Liquor	Gas	Interface Liquor	Liguor	Cas	Interface Liquor	Liguor	Cas	Gas Interface Liouor	Liouor
Property	Exposure time, months	Site 1/							1			1					
	0	-	11			1.2			23.47			2.8			8.0		
ų		1	1.1	1.3	1.3	1.1	1.0	1.0	3.2	3.1	3.1	2.3	2.5	2.3			0.7
181	•	8	1.3	#.4	1.4	1:1	1.1	1.1	3.0	3.0	3.0	5.6	5.6	5.6			0.8
19.		3	7.	1.4	1.3	1.1	1.1	1.0	3.5	3.2	3.5	2.4	2.4	2.3		,	0.7
		1	1.5	1.3	1.4	1.2	1.1	1.1	2.7	3.3	3.3	2.8	2.4	2.5		,	١.
DH :	6	2	1:	1.4	# · E	1.0	1.0	1.0	3.0	3.1	3.1	2.4	2.4	2.5	•	•	0.0
		3	1.4	1.3	1.4	6.0	1.0	1.1	5.6	3.5	т т	2.3	2.6	2.4	•	,	1.0
ing		τ	1.5	1.3	1.4	1.2	1.1	1.1	3.3	2.4	2.5	2.7	2.5	2.4			0.7
	58	~	7:	1.3	4:1	1.1	1.0	1.2	2.3	2.6	2.8	5.6	2.5	2.4	•	•	1.1
		m	1.3	#. T	1.4	6.0	6.0	1.1	2.3	2.5	2.9	2.4	2.4	2.4	•	,	1.2
		4	•	•	1.4	•		1.0	•	•	3.1	•	1	5.6	•		0.8
		-	9	-0.3	0.3	9.0	0.1	*.0	5.9	#7 60	7.1	9.5	11.3	11.3	•	•	
	~	~	-1.7	-0 -2	1.3	0.0	6.0-	4.0	4.5	2.0	2.8	1.6	6.3	9.9	1	\$	8.5
•1		3	1.1	0.7	0.4	8.0-	1.5	3.7	5.5	6.1	7.2	4.6	7.5	11.5	1	•	10.0
		1	8.0	0.2	0.0	-0.5	8.0	-2.0	1.3	11.1	11.8	13.4	20.3	20.0	Ŀ		٠
	•	2	0.5	2.5	-0.1	-2.1	2.0	3.6	6.6	11.8	7.5	13.2	16.3	17.5	•		14.9
o :		3	-0.5	4.2	1.2	-0.5	-1.6	1.4	9.8	10.5	10.9	13.3	18.0	18.6		,	10.6
		1	-0.7	-1.2	-1.3	-1.8	-0.7	-1.0	8.8	6.2	1.8	2.6	5.4	2.7	Ŀ		4.4
	8	2	-1.0	1.8	-0.2	7.4	0.7	0.5	7:7	8.6	0.8	8.	7.7	7.1	•	,	0.6
r e d		m	1.8	1.0	-0.5	-1.2	0.5	2.1	10.5	10 64	7.6	5.7	12.0	8.6	6	ı	7.6
1		a	,	1	0.0		•	9	1	2	16.4	,	•	6.02	•	,	8.6

Tapia Water Reclamation Plant, Calabasas, California. Speedway Wastewater Treatment Plant, Indianapolis, Indiana. Westgate Wastewater Treatment Plant, Alexandria, Virginia USBR Laboratories, Denver, Colorado. Site 1: Site 2: Site 3: 6 ادا

TABLE 25b. TEST RESULTS - FABRIC - REINFORCED FLEXIBLE SHEETING

	Fced	Liquor			115	120	110	1	135	155	150	160	175	120		,	2.0	10.0	1	14.9	10.6	4.1	0.6	7.8	8.6
	B-6386 CSPE Mylon reinforced	Interface			•	ı	•	•	,	1		ŧ	•	1		•	•	•	1	ı	,	4	•	1	•
	Ny	9		125	,	1	-			•	•	•	1	1			•		ı	ŧ	•	-	ı	1	ı
	orced		1		340	380	340	370	370	360	360	350	350	390		11.3	9.9	11.5	20.0	17.5	18.6	2.7	7.1	8.6	20.9
	B-6468 CPE Polyester reinforced	Interface Liquor			370	380	355	350	360	385	365	365	360			11.3	6.3	7.4	20.3	16.3	18.0	5.4	7.7	12.0	•
	Polye	Cas		415	340	385	350	410	360	345	395	390	355			7.6	9./	9.6	13.4	13.2	13.3	2.6	80	5.7	•
	P	Liquor			455	445	470	485	460	780	365	410	435	455	,	1.,	2.8	7.2	11.8	7.5	10.9	1.8	8.0	9.7	16.4
(;	B-6467 CPE Nylon reinforced	Interface Liquor			760	445	470	485	455	465	350	380	375	ı		4.0	2.0	6.1	11.1	11.8	10.5	6.2	9.8	5.2	1
units	Hyl	88		505	470	440	470	405	740	390	480	345	345	,			4.5	5.5	1.3	6.6	9.8	8.9	7.1	10.5	ı
(English units)	rced	Liquor			150	160	155	165	150	160	155	180	165	150		•	0.4	3.7	-2.0	3.6	1.4	-1.0	0.5	2.1	4.8
(Eng	B-6399 EPDM Nylon reinforced	Interface			150	160	160	165	150	150	160	150	135	1		1.0	6.0-	1.5	0.8	2.0	-1.6	-0.7	0.7	0.2	,
	Ż	Cas		180	165	170	165	185	150	140	180	170	140				0.0	-0.8	-0.2	-2.1	-0.2	-1.8	1-4.7	-1.2	ı
	rced	Liquor			200	202	200	210	205	210	205	202	205	210			7	7.0	0.0	-0.1	1.2	-1.3	-0.2	-0.2	0.0
	B-6464 Butyl ylon reinforced	Interface			200	205	210	200	205	200	200	200	205	1			.0-	0.7	0.5	2.5	4.2	-1.2	1.8	1.0	
	¥	Gas		215	210	200	205	220	210	205	225	205	200	•	4	; ;	-1.		-0.8	0.5	-0.2	-0.7	-1.0	8	ı
			Site 1/		1	7	3	-	7	3	1	2	9	,	-	- (7	_	-	7	3	-	7	n	∢
	Material	Exposure	Exposure time, months	0		n			•			58				•	<u> </u>			•			28		
			Property		4	18	z ua	47	/q	1 33	10	8					•1		eų es					đ	

1/ Site 1: Tapia Water Reclamation Plant, Calabaeas, California Site 2: Speedvay Wastewater Treatment Plant, Indianapolis, Indiana Site 3: Westgate Wastewater Treatment Plant, Alexandria, Virginia Site 4: USBR Laboratories, Denver, Colorado

TABLE 26a. THST RESULTS - RIGID POLYMERS

(metric units)

Exposure Exposure Light	Exposure	Exposure Cas Interface Liquor Cas Interface Liquor Cas	169.1 194.3 134.1 194.0 177.7 143.2 140.9 140.9				Liquor 132.5 102.4 133.3 133.3 121.9 112.7	mammin am	
Exposure	Coperty Lines Continue Cast	Coperty Class Cl	169.1 194.3 134.1 177.7 177.7 174.0 170.9 140.9			, , , , , , , , , , , , , , , , , , , ,	Liquor 132.5 102.4 133.3 121.9 113.3	m a m m m m a a m	68. 45. 66. 92. 72.
1	100 100	108.3 169.1 166.3 194.3 153.4 174.2 170.5 115.2 110.2 194.3 153.4 174.2 170.5 110.2 194.3 114.8 101.2 194.3 198.8 133.3 194.3 114.8 101.2 194.5 194.3 198.8 133.3 194.3 114.5 194.	169.1 194.3 134.1 177.7 143.4 174.2 140.9 140.9				132.5 102.4 139.7 133.3 12.7 112.7	71.3 58.1 52.3 61.3 74.3 90.5	68.8 45.4 45.4 66.6 92.1 92.5
108.3 1 108.3 159.1 166.3 159.1 174.2 170.5 166.3 132.5 58.1 3	100 100	108.3 169.1 145.1 145.1 145.1 170.5 153.4 174.2 170.5 155.2 150.2 150.2 150.2 150.2 150.3 150.8 150.3 150.8 150.3 150.8 150.3 150.8 150.3 150.8 150.3 150.8 150.3 150.8 150.3 150.8 150.3 150.8 150.3 150.8 150.3 150.8 150.	169.1 194.3 134.1 154.0 177.7 143.4 140.9 140.9				132.5 102.4 139.7 133.3 121.9	71.3 58.1 52.3 61.3 74.3 90.5	66.6 66.6 80.7 92.1 92.5
3 1 97.7 130.1 106.3 194.3 153.4 174.2 170.5 166.3 132.5 52.3 3 3 4.3 114.8 101.2 134.1 142.6 140.3 98.6 123.0 102.4 4 111.6 114.1 107.2 140.3 144.5 145.6 115.6 115.0 113.7 5 113.6 113.5 113.7 113.0 114.3 114.2 115.6 115.0 113.3 113.3 5 113.6 113.6 114.1 107.2 140.9 146.1 115.0 112.7 5 113.6 114.1 107.2 140.9 144.7 162.6 115.6 115.0 112.7 5 113.6 114.1 107.2 140.9 144.7 162.6 113.7 119.0 121.9 7 113.6 114.1 107.2 140.9 144.7 162.6 113.3 142.0 112.7 8 113.6 119.8 94.4 140.9 184.7 162.6 134.3 142.0 147.2 8 2 1.90 1.88 2.20 2.42 2.97 2.39 1.41 8 2 2 2 2.84 2.84 2.84 2.84 2.85 2.84 2.87 2.39 1.41 8 2 2 2.85 2.84 2.87 2.92 2.42 2.37 2.39 1.41 9 2 2 2.85 2.84 2.87 2.92 2.45 2.97 2.39 1.41 9 2 2 2.85 2.84 2.85 2.84 2.87 2.97 2.97 2.97 9 2 2 2.95 2.97 2.97 2.97 2.97 2.97 1 1.94 1.84 2.20 2.47 2.92 2.44 2.84 2.84 2.84 2.84 2.85 2.84 2.85 2.84 2.85 2.84 2.85 2.84 2.85 2.84 2.85	Second Street Second Stree	State Speedway Wastewater Treatment Part Pa	194.3 134.1 154.0 177.7 143.4 174.2 140.9 140.9				132.5 102.4 139.7 133.3 121.9 112.7	71.3 58.1 52.3 61.3 74.3 90.5	68.8 45.4 66.6 92.1 92.5
Steel Tapia Water Reclamation Plant, Calabase, Caries Steel St	Second	Steel Stee	134.1 154.0 177.7 143.4 174.2 140.9 146.3				132.5 102.4 133.3 121.9 112.7	58.1 52.3 61.3 74.3 90.5	68.8 45.4 66.6 80.7 92.1 72.7 92.5
10	Secondary Master Reclamation Plant, Calabasas, California. Secondary Master Reclamation Plant, Indianapolis, Indiana, 1982, 1987	Secondary Wastewater Treatment Plant, Calabasas, California, Secondary Wastewater Treatment Plant, Indiananonia 25	154.0 177.7 143.4 174.2 140.9 146.3				133.3 121.9 112.7 113.3	52.3 61.3 74.3 90.5 97.1	45.4 66.6 80.7 92.1 92.5 92.5
10	10	11.0 107.9 123.4 177.7 166.6 178.4 111.9 2	177.7 143.4 174.2 140.9 140.9				133.3	74.3 90.5 97.1	92.1 92.1 72.7 92.5
28	28 119.2 113.5 103.0 149.0 146.3 132.7 119.0 123.9 74.5 119.0 112.7 197.1 119.0 112.7 119.0 112.7 119.0 112.7 119.0 112.7 119.0 112.7 119.0 112.7 119.0 112.7 119.0 112.7 119.0 112.7 119.0 112.7 119.0 112.7 119.0 112.7 119.0 112.7 119.0 112.7 119.0 112.7 119.1 112.7 119.0 119.2 146.3 113.2 157.3 113.5 140.9 140.9 147.1 162.6 1134.3 142.0 112.7 140.9 119.7 140.9 114.7 162.6 1134.3 142.0 140.9 127.0 89.6 119.2 140.9 184.7 162.8 113.6 140.9 127.0 89.6 11.9 1.90 1.88 1.88 1.81 2.81 3.21 2.73 1.46 2.20 1.46 2.20 1.46 2.20 1.46 2.20 1.89 1.56 2.20 1.89 2.09 1.89 2.09 1.89 2.01 2.49 2.48 2.85 2.68 2.48 1.88 1.77 1.86 2.00 1.85	28 113.5 118.5 118.6 148.4 148.0 146.3 132.7 186.5 118.6 118.6 118.8 140.9 145.4 142.0 146.6 118.6 118.8 140.9 145.4 140.2 145.6 115.6 118.8 140.9 145.4 140.9 145.4 140.0 184.7 162.6 134.3 126.2 109.0 119.2 146.3 131.2 157.3 133.6 135.6 136.3 13.6 136.4 146.3 131.2 157.3 133.6 136.6 136.5 136.	143.4 174.2 140.9 146.3				121.9	90.5	92.1 92.1 92.5
28 11.0 11.0 11.0 11.0 11.0 11.0 11.0 11.	28 113.6 114.1 107.2 164.5 135.6 115.6 115.0 112.7 97.1 112.6 118.8 114.1 107.2 164.5 135.6 115.6 115.0 112.7 97.1 112.6 118.8 118.4 140.9 145.4 142.0 119.2 143.3 131.2 143.3 143.3 143.3 143.3 143.3 143.3 143.3 143.3 143.3 143.3 143.3 143.3 143.3 143.3 140.9 140.9 140.4 142.0 140.9 140.0 140.9 140.0 140.9 140.0	28 112.6 118.1 107.2 140.9 145.4 142.0 109.6 115.6 115.6 115.6 118.1 100.2 140.9 145.4 142.0 109.6 145.4 140.9 184.7 162.6 1109.6 119.2 146.3 131.2 157.3 133.5 133.6 115.6 118.8 13.6 115.6 133.6 115.6 118.8 13.6 115.6 118.8 13.6 118.8 1.86 2.84 3.20 2.42 2.04 2.84 3.20 2.42 2.04 2.84 3.20 2.42 2.04 2.84 3.20 2.42 2.04 2.84 3.20 2.42 2.04 2.84 2.84 2.84 2.04 2.04 2.04 2.04 2.04 2.04 2.04 2.0	174.2				112.7	97.1	92.5
12.6 118.6 118.7 119.0 119.1 1142.0 119.6 112.3 113.3 71.3 3 126.2 109.0 119.1 140.9 118.7 162.6 134.3 113.3 71.3 3 126.2 109.0 119.2 1140.9 118.7 118.7 118.7 3 1 1.70 2.12 1.85 2.84 2.84 3.20 2.42 2.97 2.39 1.41 4 2.40 1.88 1.71 2.27 2.47 2.29 1.46 2.37 1.41 5 2 2.39 2.26 1.92 2.48 2.84 2.88 2.72 2.74 2.99 1.54 5 2 2.39 2.26 1.83 2.40 2.42 2.97 2.20 1.85 5 2 1.90 1.88 1.86 2.58 2.48 2.88 1.77 1.86 2.02 5 2 1.90 1.96 1.51 2.45 2.76 1.93 2.00 1.85 7 2 2.18 1.88 2.15 2.48 2.84 2.84 2.84 2.84 7 2 2 2.94 2.95 2.94 2.95 2.97 8 2.15 2.15 2.15 2.45 2.75 2.54 2.55 2.75 8 2.15 2.45 2.75 2.60 2.46 1.86 2.95 9 2 1.90 1.96 1.51 2.45 2.76 2.94 2.55 2.76 9 2 2.18 1.88 2.91 2.45 2.75 2.54 2.55 1.76 9 2 2.18 1.88 2.91 2.45 2.94 2.55 1.76 9 2 2.18 2.45 2.75 2.54 2.55 2.04 1.80 9 2 2 2.18 2.45 2.45 2.55 2.60 2.45 1 2 3 2.16 3.85 2.45 2.55 1 2 3 2.55 3.55 1 2 3 2.45 2.55 1 2 3 2.55 3.55 1 2 3 2.55 1 3 3 3 1 3 3 3 1 3 3 3 3 4 3 3 4 5 5 5 5 5 5 5 5 6 7 5 5 7 7 7 6 7 7 7 6 8 7 7 7 8 7 7 7 9 7 7 7	28 2 112.6 118.8 19.4 140.9 145.4 142.0 109.6 112.3 113.3 71.3 112.6 118.8 19.4 140.9 149.7 162.6 134.3 142.0 145.2 80.9 127.0 119.2 140.9 184.7 162.8 134.3 142.0 145.2 80.9 127.0 19.6 118.2 157.3 131.6 140.9 127.0 89.6 12.8 1 1.70 2.12 1.85 2.84 2.84 3.20 2.42 2.97 2.97 1.46 2.24 1.99 1.41 2.27 2.47 2.29 1.46 2.24 1.99 1.55 2.39 2.26 1.92 2.61 2.40 2.42 2.97 2.97 1.56 2.97 1.56 2.00 1.85 1.89 2.57 2.60 2.46 1.88 1.77 1.86 2.00 1.85 2.78 2.78 2.78 2.84 2.87 2.00 1.85 2.91 2.45 2.78 2.84 2.88 2.01 1.92 2.61 2.45 2.78 2.84 2.83 2.52 1.78 2.84 2.85 2.84 2.88 2.01 2.92 2.61 2.40 2.42 2.53 2.52 1.78 2.91 2.45 2.78 2.84 2.85	28 2 112.6 118.1 140.9 145.4 142.0 109.6 145.4 142.0 109.6 145.4 142.0 109.6 145.4 140.9 145.4 140.9 184.7 162.6 134.3 126.2 109.0 119.2 146.3 131.2 157.3 133.6 136.6 134.3 131.2 157.3 133.6 136.8 13.0 136.9 148.2 148.3 13.0 148.2 148.3 148.3 148.3 148.3 149.4 1.84 2.26 2.84 2.84 3.20 2.42 2.04 1.45 2.29 1.46 2.42 2.04 2.04 2.42 2.04 2.04 2.42 2.04 2.04	140.9		-		113.3	71.3	92.5
1.00	100 100	3 126.2 119.0 119.2 140.9 184,7 162.6 134.3 0	146.9		-		-		000
10	19.00 19.0	10	146.3				145.2	Bo o	,
1	1,00	10.54 2.40 1.05.4 2.20 2.20 2.20 2.20 3.2 3.2 3.4 3.4 3.2 3.4	-	77.	-		127.0	80.5	
3 1 1.70 2.12 1.85 2.84 3.20 2.20 2.20 1.59 1.41 3 1 1.70 2.12 1.85 2.84 3.20 2.42 2.97 2.39 1.41 3 1.62 1.83 1.83 2.81 3.21 2.73 2.28 2.97 2.39 1.41 4 2 2 3 2.26 1.92 2.56 3.17 2.92 1.75 1.54 2.20 1.65 5 2 2.39 2.26 1.92 2.61 2.40 2.42 2.92 2.50 1.85 5 2 3 2.35 1.88 1.86 2.58 2.48 2.88 1.77 1.86 2.92 5 2 1.90 1.90 1.51 2.45 2.76 1.93 2.00 1.92 5 2 1.90 1.96 1.51 2.45 2.72 2.24 2.53 2.52 1.78 6 2 1.90 1.96 1.51 2.48 2.67 1.89 2.43 2.04 1.80 7 3 2.18 1.88 2.01 2.31 2.48 2.67 1.89 2.43 2.04 1.80 7 3 2.18 1.84 2.16 2.48 2.67 1.89 2.43 2.04 1.80 8 2.15 2.48 2.64 2.55 2.04 1.80 8 2.15 2.48 2.64 2.55 2.04 1.80 9 2 2 2 2 2 2 2 2 1 2 3 2 2 2 2 2 1 2 3 2 3 2 3 1 2 3 3 3 3 1 3 3 3 3 1 3 3 3 1 3 3 3 1 3 3 3 1 3 3 3 3 4 3 3 4 5 5 5 5 6 7 3 7 7 6 7 7 8 7 8 7 7 7 9 7 7	2.20 2.20 2.40 2.84 2.84 3.20 2.42 2.97 2.39 1.41 2.81 3.20 2.42 2.97 2.39 1.41 2.81 3.20 2.42 2.97 2.39 1.41 3.20 2.42 2.97 2.39 1.41 3.20 2.24 2.83 1.41 2.27 2.47 2.29 1.46 2.24 1.98 1.56 2.37 1.71 2.27 2.47 2.29 1.46 2.24 1.98 1.56 2.37 1.71 2.56 2.40 2.42 2.58 2.68 2.48 1.88 1.77 1.86 2.00 1.85 2.57 2.60 2.46 1.86 1.93 2.00 1.85 2.57 2.60 2.46 1.86 1.93 2.00 1.95 2.16 2.18 1.88 2.01 2.48 2.67 2.48 2.53 2.52 1.78 2.18 1.88 2.01 2.45 2.75 2.60 2.46 1.86 1.93 2.00 1.95 2.16 2.3 2.56 2.48 2.53 2.52 1.78 2.18 1.88 2.01 2.41 2.48 2.67 1.89 2.43 2.52 1.78 2.14 2.31 2.48 2.67 1.89 2.43 2.51 1.78 2.04 2.53 2.54 2.55 2.54 2.	1			-		102.2		6.10
3 1 1.70 2.12 1.85 2.84 2.84 3.20 2.42 2.97 2.39 1.41 2.51 2.73 2.28 1.40 2.84 2.84 2.84 2.84 2.85 3.17 2.27 1.40 2.29 1.40 1.85 1.55 3.17 2.73 2.28 2.15 2.37 1.41 2.51 3.20 2.56 2.40 1.40 2.20 1.40 2.20 1.67 2.20 1.67 2.80 2.48 2.87 2.20 1.67 2.20 1.67 2.20 1.67 2.20 1.67 2.20 1.67 2.20 1.67 2.20 1.67 2.20 1.67 2.20 1.85 2.35 1.88 1.86 2.56 2.48 2.48 2.84 2.85 2.00 1.85 2.20 2.85 2.85 2.90 1.85 2.90 2.85 2.90 1.85 2.90 2.85 2.90 2.90 2.90 2.90 2.90 2.90 2.90 2.90	3 1.70 2.12 1.85 2.84 2.84 3.20 2.42 2.97 2.39 1.41 3.50 2.84 2.84 2.84 2.84 2.84 2.84 2.87 2.29 1.46 2.24 1.99 1.81 2.27 2.47 2.29 1.46 2.24 1.99 1.56 3.17 2.27 2.40 2.40 2.40 2.24 1.99 1.67 3 2.35 1.88 1.86 2.86 2.48 1.88 1.77 1.86 2.00 1.85 2.00 3.17 3.20 2.61 2.40 2.42 2.04 2.02 2.00 1.85 2.02 2.03 2.57 2.60 2.46 1.86 1.93 2.00 1.85 2.02 3 2.18 1.88 2.01 2.41 2.45 2.72 2.04 2.53 2.52 1.78 2.18 1.88 2.01 2.41 2.45 2.72 2.04 2.53 2.52 1.78 2.18 1.88 2.01 2.41 2.48 2.67 1.89 2.43 2.52 1.78 2.14 2.33 2.52 1.78 2.04 2.33 2.52 1.78 2.04 2.33 2.52 1.78 2.04 2.33 2.55 1.30 2.43 2.04 1.80 2.43 2.04 2.30 2.43 2.04 2.30 2.43	3 1 1.70 2.12 1.85 2.84 2.84 3.20 1 1.90 1.88 1.71 2.27 2.47 2 2 3 1.62 1.83 1.83 2.81 3.21 2.73 2 2 3 2.26 1.92 2.58 3.17 2.29 2 2 3 2.26 1.92 2.51 2.40 2.42 3 2.35 1.88 1.86 2.58 2.68 2.48 3 2.35 1.89 2.09 1.89 2.57 2.60 2.46 3 2 1.90 1.96 1.51 2.45 2.78 2.75 Site 1: Tapla Water Reclamation Plant, Calabasas, California. Site 2: Speedway Wastewater Treatment Plant. Indianacolic Trains							
3 2 1.90 1.88 1.71 2.74 2.84 3.20 2.42 2.97 2.39 1.41 1.62 1.83 1.83 2.81 2.47 2.29 1.46 2.24 1.98 1.56 2.84 2.85 2.15 2.73 2.28 2.15 2.73 1.71 2.71 2.72 2.84 2.85 2.15 2.73 1.71 2.71 2.72 2.84 2.85 2.15 2.73 1.71 2.71 2.72 2.84 2.85 2.15 2.73 1.71 2.85 2.86 2.48 2.89 2.80 2.80 2.80 2.80 2.80 2.80 2.80 2.80	3 2 1.90 1.88 1.71 2.74 2.84 3.20 2.42 2.97 2.39 1.41 1.95 1.62 1.83 1.83 2.81 3.17 2.73 2.28 2.15 2.73 1.71 2.71 2.71 2.71 2.71 2.71 2.72 1.46 2.24 1.98 1.56 2.88 3.17 2.92 1.75 1.54 2.20 1.67 2.90 1.85 2.96 2.48 2.88 2.88 2.88 2.88 2.88 2.88 2.88	3 2 1.90 1.88 1.71 2.73 2.84 3.20 2.9 3.20 3.20 3.20 3.20 3.20 3.20 3.20 3.20	1		_		i dagag	1.59	
2 1.62 1.83 1.84 2.20 2.58 2.73 2.28 2.15 2.37 1.71 2.29 1.46 2.24 1.98 1.56 2.37 1.71 2.80 2.80 2.15 2.37 1.71 2.80 2.80 2.40 2.42 2.04 2.20 2.00 1.67 2.80 2.48 1.88 1.77 1.86 2.02 2.00 2.00	2 1.62 1.83 1.84 2.20 2.73 2.28 1.46 2.24 1.98 1.56 2.37 1.71 2.29 2.64 2.27 2.73 2.28 2.15 2.37 1.71 2.95 2.8 2.15 2.37 2.70 2.58 3.17 2.99 2.04 2.02 2.00 1.67 2.00 2.02 2.00 1.67 2.00 2.02 2.00 1.67 2.00 2.02 2.00 1.67 2.00 2.02 2.00 1.67 2.00 2.02 2.00 1.67 2.00 2.02 2.00 1.67 2.00 2.02 2.00 1.67 2.00 2.02 2.00 1.67 2.00 2.02 2.00 1.92 2.00 2.02 2.00 1.92 2.00 2.02 2.00 1.92 2.00 2.02 2.00 1.92 2.00 2.02 2.00 1.92 2.00 2.02 2.00 1.92 2.00 2.02 2.00 1.92 2.00 2.02 2.00 1.92 2.00 2.02 2.00 1.92 2.00 2.02 2.02 2.00 2.02	3 1.62 1.83 1.43 2.47 2.29 2 2.39 2.26 1.92 2.63 3.17 2.92 2 2.39 2.26 1.92 2.61 3.17 2.92 2 2.39 2.26 1.92 2.61 2.40 2.42 2 2 3.9 2.09 1.89 2.57 2.60 2.48 3 2 3 2.09 1.89 2.57 2.60 2.48 3 2 18 1.88 2.01 2.45 2.75 Site 1: Tapla Water Reclamation Plant, Calabasas, California. Site 2: Speedway Wastewater Treatment Plant, Indianacolic Table.			-		2.39	1.41	1 46
28 2.19 1.84 2.20 2.54 3.17 2.92 1.75 1.57 1.71 1.85 2.37 1.71 1.85 2.85 2.18 2.18 2.26 2.61 2.40 2.42 2.02 2.00 1.85 2.85 2.18 1.86 2.48 1.88 1.77 1.86 2.09 1.85 2.57 2.78 2.78 2.78 2.78 2.78 2.78 2.78 2.7	2 2 39 2.26 1.92 2.58 3.17 2.73 2.28 2.15 2.37 1.71 2.73 2.28 2.15 2.37 1.71 2.72 2.39 2.26 1.92 2.61 2.40 2.42 2.04 2.02 2.00 1.85 2.8 2.18 1.86 2.48 1.88 1.77 1.86 2.00 1.85 2.78 2.78 2.78 2.78 2.78 2.78 2.78 2.78	28 2 39 2.26 1.92 2.58 3.17 2.92 2.68 3.17 2.92 2.68 2.58 3.17 2.92 2.69 2.68 2.68 2.48 2.09 1.89 2.57 2.60 2.46 2.190 1.96 1.51 2.45 2.78 2.78 2.78 2.18 1.88 2.01 2.45 2.78 2.78 2.78 2.18 2.18 1.88 2.01 2.48 2.67 2.67 2.67 2.68 2.18 2.18 1.88 2.01 2.48 2.55 3.18 2.18 2.18 2.18 2.18 2.18 2.18 2.18 2			ronnage.		1.98	1.56	200
28 2.39 2.26 1.95 2.40 2.40 2.42 2.00 1.67 2.00 1.67 2.8 2.40 2.42 2.03 2.04 2.02 2.00 1.85 2.03 2.68 2.48 2.48 2.03 2.03 2.02 1.85 2.03 2.03 2.03 2.03 2.03 2.03 2.03 2.03	26 2.39 2.26 1.92 2.61 2.40 2.42 2.04 2.02 2.04 1.67 2.20 1.67 2.8 2.40 2.42 2.04 2.02 2.00 1.85	28 2.39 2.26 1.92 2.90 3.17 2.92 2.92 2.95 2.96 2.92 2.95 2.96 2.09 1.89 2.57 2.60 2.46 2.92 3.97 2.09 1.89 2.57 2.60 2.46 2.92 3.91 2.96 1.51 2.95 2.78 2.72 3.91 2.96 2.91 2.95 2.91 2.95 2.95 2.95 2.95 2.95 2.95 2.95 2.95	1				2.37	1.71	00
28 1 1.89 2.09 1.89 2.68 2.48 2.89 1.88 2.00 1.85 2.02 2.00 1.85 2.02 2.00 1.85 2.02 2.00 1.85 2.02 2.00 1.85 2.02 2.00 1.85 2.02 2.00 2.45 2.68 2.48 2.63 2.48 2.63 2.02 2.00 1.85 2.02 2.02 2.02 2.02 2.02 2.02 2.02 2.0	28 1 189 2.95 1.88 2.56 2.68 2.48 2.09 2.00 1.85 2.02 2.00 1.85 2.02 2.00 1.85 2.02 2.00 1.85 2.02 2.00 1.85 2.02 2.00 1.85 2.02 2.00 1.85 2.02 2.00 1.85 2.02 2.00 1.85 2.02 2.02 2.02 2.02 2.02 2.02 2.02 2.0	28 2.35 1.88 1.86 2.58 2.68 2.48 1.89 2.09 1.89 2.57 2.60 2.48 2.48 2.09 1.89 2.57 2.60 2.48 2.18 2.09 1.89 2.57 2.60 2.48 2.18 2.18 1.88 2.01 2.31 2.48 2.77 2.67 2.67 2.67 2.67 2.67 2.67 2.67	-		-		2.20	1.67	200
2 1.90 1.96 2.01 2.45 2.46 1.86 1.77 1.86 2.02 1.02 2.03 2.01 2.45 2.76 2.78 2.78 2.78 2.78 2.78 2.52 1.78 2.52 1.78 2.01 1.92 2.01 2.31 2.48 2.67 1.89 2.43 2.04 1.80 2.01 2.31 2.48 2.67 1.89 2.43 2.04 1.80 2.01 2.01 2.01 2.01 2.01 2.01 2.01 2.0	2 2 1.90 1.96 2.07 2.57 2.60 2.46 1.86 1.77 1.86 2.02 1.02 2.03 2.01 1.92 2.03 2.01 1.92 2.03 2.01 1.92 2.03 2.01 1.92 2.03 2.04 2.53 2.52 1.78 2.16 2.16 2.16 2.16 2.16 2.16 2.16 2.16	Site 2: Speedway Wastewater Treatment Plant, Indiananolism 2.38 2.48 2.56 2.46 2.46 2.46 2.01 2.31 2.48 2.67 2.67 2.67 2.67 2.46 2.46 2.46 2.46 2.46 2.46 2.46 2.46			-		2.00	1.85	200
28 2 1.90 1.96 1.51 2.45 2.78 2.78 2.78 2.52 1.78 2.52 1.78 2.52 1.78 2.52 1.78 2.52 1.78 2.52 1.78 2.51 1.89 2.43 2.50 1.90 2.43 2.51 1.80 2.43 2.51 1.80 2.43 2.51 1.80 2.43 2.51 1.80 2.43 2.51 1.80 2.43 2.51 1.80 2.43 2.51 1.80 2.43 2.51 1.80 2.43 2.51 1.80 2.43 2.51 1.80 2.43 2.51 1.80 2.51 1	28 2 1.90 1.96 1.51 2.45 2.76 2.78 2.78 2.53 2.52 1.78 3 2.18 1.88 2.01 2.48 2.75 2.24 2.53 2.52 1.78 5 5 5 5 5 5 5 5 5 5	2 1.90 1.96 1.51 2.45 2.72 3 2.18 1.88 2.01 2.31 2.48 2.72 3.15 2.18 3.81 3.81 3.81 3.82 3.72 3.81	\perp			-	1.86	2.05	12
3 2.18 1.88 2.01 2.31 2.48 2.67 1.89 2.43 2.52 1.78 21te 1: Tapla Water Reclamation Plant, Calabasso California	3 2.18 1.88 2.01 2.31 2.48 2.67 1.89 2.91 1.78	3 2.18 1.88 2.01 2.34 2.55 2.16 1.92 2.55 2.56 2.5			Semino.	!	2.00	1.92	2 26
Site 1: Tapia Water Reclamation Plant, Calabass, California	Site 1: Tapia Water Reclamation Plant, Calabasas, California. Site 2: Speedway Wastewater Treatment Plant, Indianapolis, Indiana.	Site 1: Tapla Water Reclamation Plant, Calabasas, California.			eren.		2.52	1.78	300
Site 1: Tapia Water Reclamation Plant, Calabasse California	Site 1: Tapla Water Reclamation Plant, Calabasas, California. Site 2: Speedway Wastewater Treatment Plant, Indianapolis, Indiana.	Site 1: Tapia Water Reclamation Plant, Calabasas, California.					2.04	1.80	1.90
Site 1: Tapla Water Reclamation Plant, Calabasas California	Site 1: Tapia Water Reclamation Plant, Calabasas, California. Site 2: Speedway Wastewater Treatment Plant, Indianapolis, Indiana.	Site 2: Speedway Wastewa		1	·Penant		1.76	2	70.1
	2: Speedway Wastewa	2: Speedway Wastewa	116000		-		-		
eedway Wastewater Treatment Plant, Indiana	sigate Wastewater Treatment Plant, Alexandi	Westgate Wastewater Treatment Plant, Alexandr USBM Laboratories, Denver Colonal		1 1 0 -1	2.27 2.47 2.81 3.21 2.58 3.17 2.61 2.40 2.58 2.68 2.57 2.60 2.45 2.78 2.31 2.48	2.27 2.47 2.29 2.81 3.21 2.73 2.61 3.40 2.42 2.58 2.60 2.48 2.57 2.60 2.46 2.45 2.78 2.72 2.45 2.78 2.77 2.31 2.48 2.67 2.56 diana.	2.27 2.47 2.29 1.46 2.81 3.21 2.73 2.28 2.58 3.17 2.93 2.28 2.51 2.40 2.42 2.04 2.58 2.68 2.48 1.88 2.57 2.60 2.46 1.86 2.45 2.72 2.24 2.31 2.48 2.67 1.89 2.57 2.60 2.60 2.45 2.72 2.24 2.31 2.48 2.67 1.89 2.56 -	2.27 2.47 2.59 2.44 2.97 2.59 2.45 2.58 3.17 2.92 1.75 1.54 2.58 2.65 2.40 2.40 2.40 2.67 2.57 2.57 2.56 2.46 1.88 1.77 2.57 2.57 2.56 2.48 2.88 1.88 1.77 2.57 2.56 2.48 2.57 2.50 2.45 2.57 2.50 2.45 2.57 2.50 2.45 2.57 2.50 2.45 2.57 2.50 2.45 2.57 2.50 2.43 2.53 2.50 2.43 2.55 2.50 2.43 2.55 2.50 2.43 2.55 2.50 2.43 2.55 2.50 2.43 2.55 2.50 2.43 2.55 2.50 2.43 2.55 2.50 2.43 2.55 2.50 2.50 2.50 2.50 2.50 2.50 2.50	2.27 2.47 2.39 2.47 2.39 2.48 2.58 3.17 2.39 2.58 2.58 3.17 2.99 2.04 2.02 2.00 2.58 2.57 2.50 2.57 2.59 2.00 2.58 2.68 2.48 1.88 1.77 1.86 2.57 2.50 2.45 2.55 2.50 2.45 2.55 2.50 2.45 2.55 2.50 2.55 2.50 2.55 2.50 2.55 2.50 2.55 2.50 2.55 2.50 2.55 2.50 2.55 2.50 2.55 2.50 2.55 2.50 2.55 2.55

TEST RESULTS - RIGID POLYMERS TABLE 26b.

(English units)

Strain, Flexural Strangth, open of the state	15,710 14,180 17,490 13,680 16,200 16,200 17,290 18,960 16,340	18,370 16,720 16,660 15,660 18,900 16,660 16,660 16,660 16,660 16,400 16,400 16,560 16	Liquor		TOTACETE			Vinyl			E	
Exposure time, months 51te 1/2 0 4 0 1 1 1 1 1 1 1 1 1	15,710 14,180 17,490 13,680 16,200 16,200 11,290 16,340			Cas	Interface	Liquor	Gas	Interface	Liquor	**5	Interface	Liquor
2 0 m o m o m o m o m o m o m o m o m o m	15,710 14,180 17,490 17,490 13,680 16,200 18,200 18,200 16,200 16,200 16,200											
201/41 3ng	14, 180 17, 490 13, 680 16, 200 18, 960 17, 290 16, 200 16, 300			24,530			21,050			10,350		
2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	17,490 13,680 16,200 18,960 17,290 16,200		15,430	28,190	22,260	T	24,730	24,120	19,220	8,430	066.6	10,400
201/411 2 2 9 9 0 U U U U U U U U U U U U U U U U U	13,680 16,200 18,960 17,290 16,200			19,450	20,690		13,610	17,840	14,860	7,598	6,590	6,970
2m1/d1 2m2 2 20 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	16,200 18,960 17,290 16,200 16,340		.,	22,350	27,440		17,890	17,700	20,270	8,900	9,660	7,846
30 0 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	18,960 17,290 16,200 16,340	1	17,900	25,780	24,170		16,240	13,930	19,340	10,790	11,710	14,110
3uc 3 3uc 17	17,290 16,200 16,340			20,800	20,750		19,260	17,260	17,690	13,130	13,360	14,000
30 0 28	16,200		14,950	25,270	23,870		16,780	16,680	16,350	14,090	10,550	11,960
30 C S	16,340		ř	20,450	21,090	3	15,900	16,300	16,440	10,350	13,430	11,100
0 0				20,450	26,790	24,020	19,480	20,600	21,060	11,740	13,460	11,580
0 6	18,310			21,220	19,040	22,820	19,390	20,450	18,430	13,000	11,890	13,220
0 6	•		15,300		. 1	21,500	•	1	14,830	'	,	11,740
O m												
n l	2.40			2.20			2.20			1.59		
- Jue	1.70	2.12	1.85	2.84	2.84	3.20	2.42	2.97	2,39	1.41	1.48	1.72
Jue	1.90	1.88	1.71	2.27	2.47	2.29	1.46	2.24	1.98	1.56	1.20	1.20
Jue	1.62	1.83	1.83	2.81	3.21	2.73	2.28	2.15	2.37	1.71	1.99	1.64
	1.94	1.84	2.20	2.58	3.17	2.92	1.75	1.54	2.20	1.67	1.83	3.10
-	2.39	2.26	1.92	2.61	2.40	2.42	2.04	2.05	2.00	1.85	2.01	1.56
	2.35	1.88	1.86	2.58	2.68	2.48	1.88	1.77	1.86	2.02	1.72	2.07
d	1.89	2.09	1.89	2.57	2.60	2.46	1.86	1.93	2.00	1.92	2.26	5.08
28	1.90	1.96	1.51	2.45	2.78	2.72	2.24	2.53	2.52	1.78	1.36	2.32
	2.18	1.88	2.01	2.31	2.48	2.67	1.89	2.43	2.04	1.80	1.82	1.68
*	. •	,	1.92	•	1	2.56	•	•	1.76	,	ŧ	.8

1/ Site 1: Tapia Water Reclamation Plant, Calabasas, California Site 2: Speedway Wastewater Treatment Plant, Indianapolis, Indiana Site 3: Westgate Wastewater Treatment Plant, Alexandria, Virginia Site 4: USBR Laboratories, Denver, Colorado

TEST RESULTS - PROTECTIVE COATINGS ON STEEL SURFACES - SITE 1* Coating Film Defects*** Site 1 Exposure TABLE 27.

			arce 1 pyposure	
	Nominal			
Code No.**	exposure time, mo	Gas	Interface	Liquor
	Ĺ	NO LOFECTS	Wo de fectiva	111111111111111111111111111111111111111
	c			Strgue pinnead bilstering around
	61	No defects	Pinhead blistering	Slight pinhead blistering around
C-2	7	No defects	around score	score
	19		No defects	No defects
C-3	7	Slight impact damage	of teres	No defects
	19	impact	Siignt impact damage Alligator cracking	No defects
			both sides	Silgnt alligator cracking
ر ا د	7	Thin area on edge	No defects	
		03	ייי ננונו	No defects
	19	Thin area on edge	No defects	
		with corrosion		No detects
<u>.</u>	7	Corrosion on unscored	Dinhood L1:	
		- 1	around soots	Pinpoint blistering over 100 per-
	19	Corrosion over 100 per-	Correction action	cent of area
		cent of area	cent of area	Pinpoint blistering over 100 per-
0-5 0-1	7	Corrosion on edge	No dofest	cent of area
	19	o	No delects	One impacted area
8-J	7	P	One impacted area	Blisters with corrosion
		with rust		Iwo impacted areas
	19	One impacted area	One impacted area	
0		with rust	יייי ביייי מועש	Iwo impacted areas
6-5	7	No defects	No defect.	
= .	19	No defects	No defects	No defects
C-11#	7	Few breaks in coating	Film deterioration	No defects
	19	Few breaks in coating	Complete loss of film	Film deterioration Complete loss of film
* Site	-	Tania Matam na 1		mitt to 000.

* Site 1 - Tapia Water Reclamation Facility, Calabasas, California.

** See table 5 for coating identification

*** See figures 24 through 30 for typical examples of coating defects.

Exposure racks were coated with this material.

TABLE 28. TEST RESULTS - PROTECTIVE COATINGS ON STEEL SURFACES - SITE 2 1/2 Coating Film Defects 1/2 Site 2 Exposure

Code				
	nonths	\$ 8 8 0	Interface	Liquer
c-1	-	Blaters around acore		
	10		Sight blacks around acces	No defects
	50	Alisters around score	Slight blistering ground score	Con history of another
	87	Silaters around score	Siight bilatering around score	Pinpoint bilgtering
6-3		7 7 7		
	10	and	Wo defects	No defects
	20	No defects	Stignt pinhead blistering	No defects
	28	No defects	Clashe planed black-ing	No defects
			201223001000000000000000000000000000000	Mechanical demage
C-3	3	90000		
	10	No defects	Cracking on both elder	Mechanical demaga
	20	We defects	Cracking on both sides	The state of the s
	07	Alligator cracking, both sides	Severe alligator cracking	Alligator cracking, both sides
4-5	-	Mr. defects		
	10	To de fecta	No defects	No defects
	20	No defects	No defects	
	28	No defecta	Slight alligator cracking	No defects
	~ 9	No defects	Some etusion of coating	Mo deferte
	2 5	No defects	Pinhead blistering around score	Large blisters around acore
	28	3	Pinhead blistering around score	Large blisters eround score
		The printed districts, willightor cracking	farge pinhead blisters, alligator cracking	Large pinhend blisters, alligator eracking
	ſ	No defacts	No defects	
	0 9	Finhead blisters, both sides	No defects	Pinhead bilaterine armini accom
	28	Chinese blisters, both sides	Alisters around score	Piniesd biletering around acoust
		and a state of the	Large and pinpoint blisters	Film soverely deteriorated
	6	No defects	the defeate	
	10	No defects	No de fect a	No defents
	20	No defects		One chinned area by source
	٤,	(hipped on edges		Our chipped area by scare
	•	No defects	of the fact of	
	10	No defects	No defects	No defects
	02			
	97	No defects	No defects	No defects
c-10	•	No defects	No de Care	
	17	Film completely deterlorated	Severe film deterioration	No defecte
C-12		No defects	No de fecta	
	13	No defects	No defects	No defects No defects
1.7				
	12	Linear Wilsters around score	Pinhead blistering ground score	Pinhead biistering around score
			PAGOS DIMONE WITTENDER TO THE TOTAL	Pinhead bitstering around score
•1- ɔ	13	Blistering, both sides	Blistering, both sides	Mitatorios took aldos
		nitacering, norm sides	Severe pinhead blistering	Mintering, both sides
0-16	,			
		Bilecering, Concode only	# 1	

1/ Site 2 - Speedomy Wastewater Treatment Plant, Indianapolis, Indiana 2/ See Table 5 for conting identification 1/2/ See Figures 74 through 10 for typical examples of coating defects

TABLE 29. TEST RESULTS - PROTECTIVE COATINGS ON STEEL SURFACES - SITE 3 1/ Coating Film Defects 3/ Site 3 Exposure

2/ 2/ 2/ 2/	crpusure ries,	Gass	Interface	Liquor
,	911110			
Ξ		Pinhead bilinters around score	Syche Lauren attente blancatati	
	10	Pinhead bilatera pround score	Pinhead blisters around score	Plohead blisters around around
	20	Pinhead blisters around acore	(व)	Pinhead blisters around acore
	9.7	Flubesd biluters around scure	Bilatering, both aldes	Pinhead blisters, both sides
		And the state of t		
C-3	~ ;		No defects	No detects
	0.2	No defects	No defects	No defects
	23	No defects	/5 / CE	No deloces
			יים ייבירים	no de fects
C-3	r	No defects		
	01	Alligator cracking, both sides	Alligator cracking, both sides	Mechanical desays
	24	Alligator cracking, both sides	171	Mechanical damage
	;	Tribbito Cheming, ports anded	Ailigacor cracking, both aiden	Alligator cracking, both sides
7-0	·	No defects	No defects	Mo feet and
	0 2	Pinhead bilatering around acore	No defects	Finited bilaters around score
	28	Finhead blistering around acore	14/	Pinhead blisters around score
		יווייכים אויפרפנית שומפות פרסונה	No defects	Pinicad blisters around score
C-5	m	Blisterine around acore		
	01	Pinhuad blinturs, both sides	Pinhed bliness both sides	Vose arosion of costing
	20	Pinhead bifaters, both sides	31	Pinled bilsters ground score
	28	Finites d bilaters, both sides	Finhead bitaters, both sides	runked blisters, both sides
1				
	2	Modelects Pinland hilanam hosts at the	Some erosion of conting	Some erosion of coating
	20	finhead blisturs, both sides	Finited bilaters ground score	Summe crostom of coasting
	ដ	Pinkend blisters, both sides	Pinisead blisters, hoth sides	Plubead blisters, both sides
-S	~ 9	No defects	Mo defects	No defects
	2 2	Chipping stound center bole	Slight cracking due to acoring	Chipping around center hole
	2.6	Chipping around center hole	Slight cracking due to acoring	Chipping around center hole
6-3	3		No defects	No defects
	0 :		No defects	No defects
	98	No defects	(A)	No defects
				אם דבונכנים
C-10	25		/5	
	17	Film deterlorated	Film deteriorated	Film deteriorated
6-3		like da factoria		
:	12	No defects	No defects No defects	4/ No defects
C-13	12	No defects Pinhead bilstering, both wides	No defects Pinhoad blisters, both sides	$\frac{4}{P}$ inhead blisters, both sides
C-14	3	No defects Severa pinhead blistering	Pinhead bitaters, both sides Pinhead bitaters, both sides	Pinheed blisters, both addr.
		And the second s		
C-15	3	Blatering, topcost only Blatering, topcost only	Blisters, topenas only Blisters, toncone only	/4
			Many apparation described	The same and the s

1/ Site 3 - Westgate Mastewater Treatment Plant, Alexandria, Virginia 2/ See Table 5 for consting identification 3/ See Figure 2/4 through 30 for typical examples of coating defects 4/ Sample could not be retrieved for evaluation during this impection.

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TEST RESULTS - PROTECTIVE COATINGS ON CONCRETE SURFACES - SITE 1*
Coating Film Defects***
Site 1 Exposure TABLE 30.

C-1	exposure time, mo	Gas	Interface	Liquor
	7	No defects	Pinhead blistering over 100 per-	Pinhead blistering over
	19	No defects	cent of surface Pinhead blistering over 100 per-	100 percent of surface Pinhead blistering over
C-3	7	Craters on scored side	Craters on social	100 percent of surface
	19	scored	Alligator cracking, both sides	Crarers on scored side Slight alligator cracking
5- 2	7	Slight pinhead blistering	Pinhead blistering, both sides	Pinhead blistering, both
		on scored side		sides
	19	a)	Pinhead blistering both sides	Pinhead blistering, both
		on scored side		sides
C-5	7	No defects	Blisters and flaking, 100 per-	Blisters and flaking,
	,		cent of area	100 percent of area
	19	No defects	Blisters and flaking, 100 per-	Blisters and flaking,
			cent of area	100 percent of area
9-0	7		Pinhead blisters, 100 per-	Pinhead blisters,
		unsored side	cent of area	100 percent of area
	19	Impacted area,	Flaking	Pinhead blisters,
		unscored side		100 percent of area
C-7	7	Slight cratering	Slight cratering, large pin-	Slight cratering, large
	ç		head blisters	pinhead blisters
	19	Slight cratering		Slight cratering, large
			head blisters	pinhead blisters

^{*} Site 1 - Tapia Water Reclamation Facility, Calabasas, California. ** See table 5 for coating identification *** See figures 24 through 30 for typical examples of coating defects.

TEST RESULTS - PROTECTIVE COATINGS ON CONCRETE SURFACES - SITE 2*

Coating Film Defects***

Site 2 Exposure TABLE 31.

Code No.**	Nominal exposure		Interface	Liquor
	time, mo		•	e i quoi
C-1	3	No defects	No defects	No. defeat
	10	No defects	Pinhead blisters, both	No defects No defects
	20	No defects	Pinhead blisters, boti	h Pinhead blisters abound scor
	28	No defects	Large blisters	Pinpoint blisters, both
C-3	3	No defects	No defects	sides
	10	Craters	Alligator cracking, bo sides	Mechanical damage oth Slight cratering
	20	Craters	Alligator cracking, bo	oth Slight cratering
	28	Slight alligator cracki	ng Alligator cracking, bo	
C-4	3	No defects	No defects	sides No defeate
	10	No defects	No defects	No defects No defects
	20	No defects	No defects	No defects
2-5	28 3	No defects	No defects	No defects
,-3	10	No defects	Some erosion of coatin	Geneval blisteri
	10	Pinhead blisters, both	Pinhead blisters, both	Severe blistering, both
	20	sides Pinhead blisters, both sides	sides Severe blistering, bot	eidoc
	28	Pinhead blisters, both	sides Blistering, alligator	sides Severe blistering, both
-6	3	No defects	cracking	sides
	10	Severe blistering, both sides	No defects Severe blistering, both	No defects h Large blisters around
	20	Severe blistering, both sides	sides Severe blistering, both	CONO
	28	Severe blistering, both sides	sides Severe blistering, both	e i doc
-7	3	Nc defects	sides	sides
	10	No defects	No defects No defects	No defects
	20	No defects	No defects	No defects
	28	No defects	No defects	No defects
-9	3	No defects	No defects	No defects No defects
	10	No defects	No defects	No defects
	20	No defects	No defects	No defects
-12	28	No defects	No defects	No defects
-12	3 10	No defects	No defects	No defects
-13	3	No defects	No defects	No defects
13	12	No defects	No defects	Blisters, both sides
14	3	Large blisters No defects	Large blisters	Blisters, both sides
	12	Pinhead blisters	No defect Large and pinhead	Blisters around score Large blisters, both sides
15	3	No defects	blisters No defects	
	12	Alligator cracking	No defects	No defects
16	3	No defects	Alligator cracking No defects	Alliigator cracking
	12	Few blisters, top- coat only	Few blisters, top- coat only	No defects Blisters, topcoat only

^{*} Site 2 - Speedway Wastewater Treatment Plant, Indianapolis, Indiana. ** See table 5 for coating identification *** See figure 24 through 30 for typical examples of coating defects.

TABLE 32. TEST RESULTS - PROTECTIVE COATINGS ON CONCRETE SURFACES - SITE 3 $\underline{1}/$ Coating Film Defects $\underline{3}/$ Site 3 Exposure

	Parie !			
7	all markets	å		1
å				
3			No defects	No defects
	. 2		Pinheed biinters, both sides	Pinhead bilaters, both sides
	2	Pinhead bileters, beth sides		Pighesd bilecers, beth cides
	ñ		FIRMSON WINCHES, ONCH PLONE	Cimient Filblish work bloom
:			Section and relative	Belanical dense
ร	7 5		Allianter cracking, both sides	Nechanical demage
	2		7	Alligator cracking, both sides
	33	Alligator cracking, both sides	Alligator eracking, both sides	Alligator cracking, both sides
3	-		No defects	Market Misters street access
	2 %	Fighted bliscories, both sides		
	n		Pimpelst biluters, both eldes	Pinhead bilatore around scere
3	•		Coating eroded	Conting proded
	21		Fights 6 bisters, won slow	Pisheod bileters, both sides
	2 25	Pinhead blisters, both sides	Pinkond bitsters, both sides	Pishead blisters, both sides
3	•		Casting erubad	Ceating croded
	2	Plabe od blisters, byth sides	Pisheed bilature, both sides	Pinkeed bitsters around score
	21		All and Mileson Leaf of the	Fighesd bileters around score
	a	Fishcad blisters, well sides	righten tileters, seen sisse	Transfer transfer to the second secon
3		4	22.2	Bo defects
	2		Cratering	Cratering
	2			Cretering, one blinter, unecored side
	Ą	Cratering	Characterist	CIRCLES, cas elected, second of the
;			1 1 (11)	
	. 2	l A	No defects	No defects
	2	4		No defects
	n	_		
1			1 de feets	7
	מי		Do defects	No defects
;			1	7
3	מי	Large biloters	Large blisters	Large bilators
1.5	C-14 3	No defects Plumind blisters, both eldes	No defects Pinhead blisters, both sides	by Pishonel blisters, both sides
2.13	* ¤	#11cht obrasion demand	Blistering graund score Blisters, both sides	A. A. A. S. B.
÷	~ 3	Slight blistaring, tepcont only slight blistaring, topcont only	slight blistering, topcost only Slight blistering, topcost only	4/ Slight blintering, topcoat anly
	!			

1) site 3 - Westgate Westerniter Treatment Plant, Alexadetla, Virginia
1 Ses Table 2, for conting identification
2) See Highes 20, through 30, for tryical summeries of conting defects
4) Seeple comid and he retrieved for evaluation during this inspection

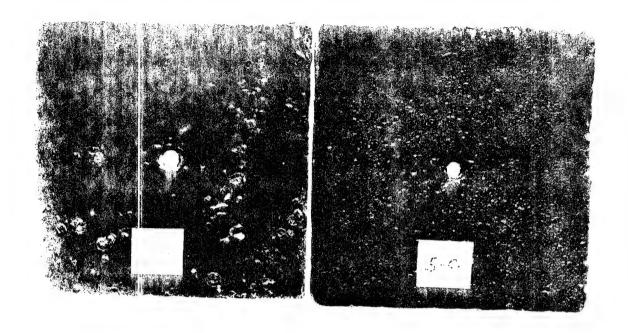


Figure 24. Blistering of proprietary butyl coating (No. C-6) on steel (left) and concrete substrates.

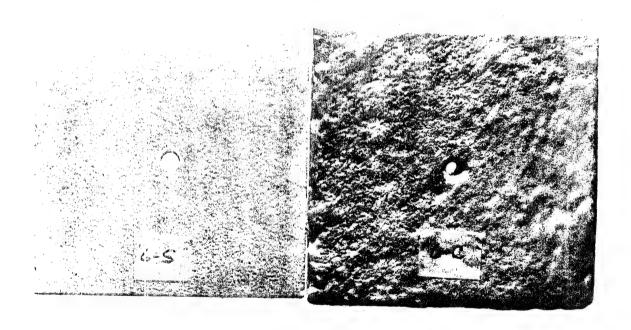


Figure 25. Defect-free proprietary urethane coating (No. C-9) on steel (left) and concrete substrates. Roughness is characteristic of application.

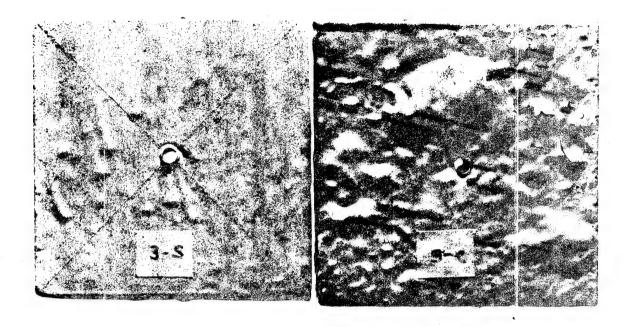


Figure 26. Blistering of proprietary, one-component urethane coating (No. C-13) on steel (left) and concrete substrates.

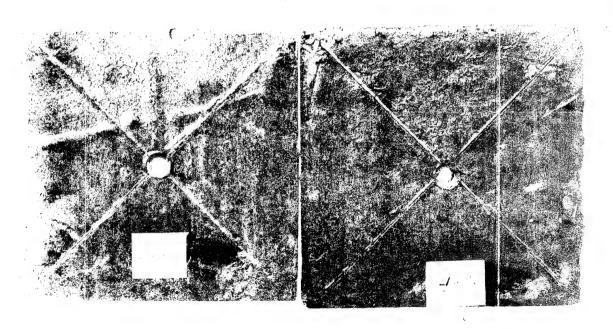


Figure 27. Cracking of coal-tar enamel coating (No. C-3) on steel (left) and on concrete substrates.

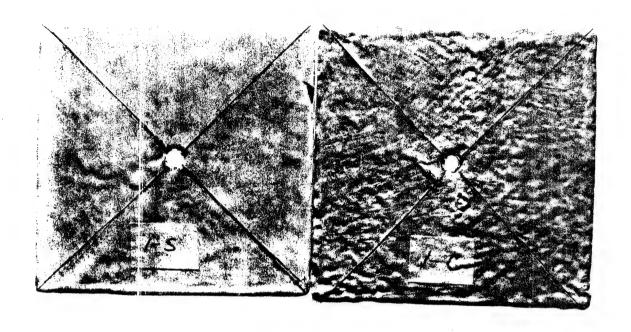


Figure 28. Defect-free phenolic-epoxy coating (No. C-12) on steel (left) and concrete substrates.

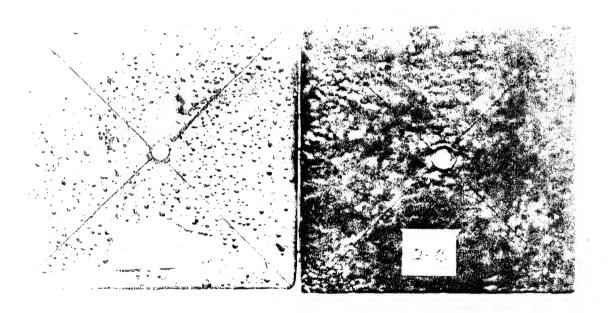


Figure 29. Severely blistered prorietary urethane coating (No. C-14) on steel (left) and concrete substrates.

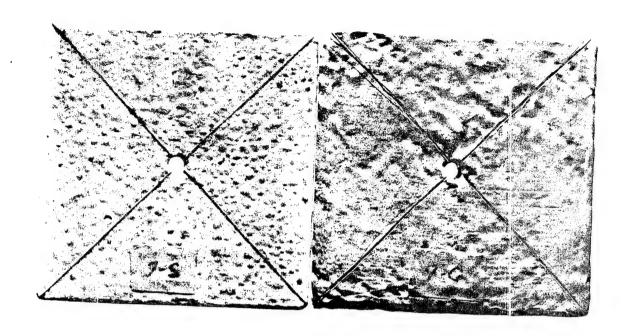


Figure 30. Blistering (topcoat only) of proprietary phenolic-epoxy coating (No. C-16) on steel (left) and concrete substrates.

TABLE 33. EVALUATION SUMMARY - PROTECTIVE COATINGS FOR STEEL SURFACES

Performance Rating 1/

site apposure as aterface iquor as aterface iquor	1 1 2 1 1 1	19 mag	3 μος 1	302 9		81to 2 <u>)</u> / 12 mas 1		2	26 mos 2	3 800		10 mas		17 mos			Average 5/	Higheo 6/
ss nterface iquor es nterface iquor	1 1 2 1 1 1	1 2 2 2 1 1 1	3		2 2	•	-	2		 				17 806				<u>5</u> /
nterface iquor ss nterface iquor ss nterface	1 1 1 1 2	. 2 2 1 1	1	es.	2				2	١,		_					1	
iquor sterface iquor sterface	1 1 1 2	1 1	1			-	_			4	40	2	-	-	2	2	1.7	i
es nterface iquor as nterface	1 1 1 2	1 1	1	-			_	2	2	2	Man	2	-	-	-	4	2.7	
nterface iquor as aterface	1 1 2	1	1							2			-		2	4	3.0	3.0
iquor as aterface	2		1 2	-	1	-	_	1	1	1	-	1	_	-	1	1	1.0	l
as aterface	2	1	1 8	~	3	-	-	3	3	1	-	1	-	•	-	1	1.7	!
terface	2	-			1_	-				1		1	-		_1_	1	1.3	1.7
		2		-	1	•	-	1	4	1	-	4	-	-	4	4	3.3	
lquor	2	•	į į	-	4	-	~	4	4	4	-	4	-	-	-	Ä	4.0	
	2							2	4	2	-			-	2	4	4.0	4.0
1.0	2	2		••	1	-	-	1	1	1	-	2	-	-	2	2	1.7	
terface	1	1	1	-	1	-	-	- i	š	ī	-	ī	-	-	-	i	1.7	
quor	1	11			1				1	1	-	2		-	2	2	1.3	1.7
18	4	4	1	_	1		_	1		2	-	4	-	_	4		4.0	
terface	2	4	1	-	2	-	-	2	- i	2	_	Ä	-	_	-		4.0	
quor	4	4			2	-		2	-	2	-	2			2	4	4.0	4.0
	2	2		-	3	40	-	3	4	1	_	4	-	_	4	4	3.3	
terface	1	4	í	-	1	-	-	2	3	2	_	ž	-	_	Ξ	- 1	3.7	
quop		4					<u> </u>		4	2		2	-	•		4	4.0	4.0
	2	2	1	-	1	-	-	1	2	1	-	2	_		2	2	2.0	
terface	2	2	i	-	ī	-	_	ī	ī	ī	_	2	-	-	-	2	1.7	
quor	2				1	-		2	2	1		2	-	-	2	2	2.0	2.0
. 1	1	1	1	_	1	-	-	1	1	1	-	1			1	1	1.0	
terface	1	1	Ī		1	-	44	ī	i	î	_	i	-	-	-	i	1.0	
quor	1	_1			1			1	1	1	-	1		_	1	_i	1.0	1.0
	***	_	A.18	ı		-	4	•	- 1	*	1	_		4	_	-	4.0	
terface	-	-	4.9	1	**	. 44	å	-	-	_	-	-	-	•	-	- 1	4.0	
TOUT			-	1		**	4	-		-	1	-	-	4	-	-	4.0	4.0
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uor			<u>i</u>	_		6	-	-	-	-			<u> </u>	-	-	=	4.0	4.0
	-																	
erface			n n	-						u								
erface	-	-	.3 3	-	-		-	-	-	í	_	-	3	-	-		3.0	
	ace	ace -	ace	ace A	ace &	ace 6	sce 4 4 4	ace 4 - 4 - 4 - 5 - 6 - 6 - 6 - 6 - 6 - 6 - 6 - 6 - 6	sce 4 4 4 4	ace 4	sce 4 1	sce 4 1 - 4 4 4	sce 4 1 4 6 6 6	ace 4 4 4 4 4 4	ace 4	ace 4	sce 4 4 4 4 4	ace 4 4 4.0

^{1/} Assigned as follows: 1 - No defects
2 - Defects patributable to application, scoring, or machanical demands
3 - Minor or for defects
4 - Severa defects
4 - Severa defects
3/ Tapia Water Reclamation Facility, Calabasas, California
3/ Speedway Wastewater Treatment Finnt, Indianapolis, Indiana
4/ Vestgate Wastewater Treatment Finnt, Alexandria, Virginia
5/ Average of ratings assigned after final evaluation at sites emposed
6/ Highest (superical value) of average ratings for given cooting

EVALUATION SUMMARY - PROTECTIVE COATINGS FOR CONCRETE SURFACES Performance Rating 1/TABLE 34.

Code	Site	Site	e 1 <u>2</u> /		S	Site $2\frac{3}{}$				J	Site 3 4/		:		
No.	e	7 mos	19 mos	3 mos	10 mos	12 mos	20 mos	28 mos	3 тоѕ	10 mos	12 mos	20 mos	28 mos	Average 2/	Highest <u>b</u> /
C- 1	Gas		П «		17	i i	Η,	1		7	1 1	4	4 '	2.0	
	Liquor	7 7	t t		t -1		2	7 -7		7 7		1 7	7 7	4.0	4.0
C- 3	Gas	7 7	. 2	~ ·	2		2	е.	e 1	4	1	4	4	3.0	
	Interface	7 7	7 7	2	5 4		7 7	7	3	2	1 1	+ 7	4	4.0	4.0
7 -5	Gas	2	2	r-1	-	1	-	7	П	4		7	7	2.3	
	Interface	7 7	77			1 1	7 -			7	l J	1 3	7 7	3.0	3.0
ر د	Gas	-	~	-	7	1	7	7	_	19	1	7	4	3.0	
	Interface Liquor	7 7	7 7	7	4 4	ıı	7 7	7	2 2	4 4	1 1	1 45	33	4.0	4.0
9 -J	Gas	2	2	-	7	,	7	7	-	4	,	7	7	3.3	
	Interface	7 7	7 7		7	1 1	7 7	7 7	2 2	7 7	1 1	- 2	7 7	3.3	4.0
C- 7	Gas	2	2	-	-	1	-	-	-	,		2	2	1.7	
	Interface	. 4	1 47 1	٠	. ~ .	1	•			1 7 1	1	. 1 (171	2.3	,
	Liquor	4	4	-	1		1	-	-	2	1	3	3	2.7	2.7
6 -0	Gas Interface	+ 1	. t f			1 1				₩ 1	1 1	et 1		1.0	
	Liquor	-	'	-	-	1	7	1	-1	1	-	-	1	1.0	1.0
C-12	Gas	,	1		,	1	1	,		1	H	ı	ı	1.0	
:	Interface	1 1			1 #	~ ~	1 1	1 1	٦,	1 1		1 1	1 1	1.0	1.0
C-13	Gas	<u>'</u>		1	,	-			-	,	4		'	2.5	
	Liquor	1 1	, ,	7	1 1		1 1	1 1	et 1	1 1	4 4	1 #	1 1	2.5	4.0
C-14	Gas	,	ı		ı	4		,	-	t	7	ı	ı	4.0	
	Interface	1 1	1 1	1 7		4 4	1 1	+ 1	۰ - ۱	1 t	4 4	1 1	1 1	0.4	4.0
c-15	Gas	,	,	-	'	7	,		,						
	Interface	,	1	-	1	. 4	1	1	7 7	1 1	7 • 7	ı	1 1	0.4	
	Liquor	-			1	4	-	,	-	-	4	,	,	4.0	4.0
C-16	Gas	1	1	-	,	٣	1	ı	ŕ	,	۳		,	c	
	Interface	1 1	1 1		ž į	en c	1	ı	3	ı	ı en e	ı	,	3.0	
1/ Ass	1/ Assigned as follows:	OWS:	9	defects					,	-	5		-	3.0	3.0

^{1/} Assigned as follows: 1 - No defects
2 - Defects attributable to application, scoring, or mechanical damage
3 - Minor or few defects
4 - Severa defects
5/ Tapia Water Reclamation Facility, Calabasas, California
3/ Speedway Wastewater Treatment Plant, Indianapolis, Indiana
4/ Westgate Wastewater Treatment Plant, Alexandria, Virginia
5/ Average of ratings assigned after final evaluation at sites exposed
6/ Highest (numerical value) of average ratings for a given coating

No defects - Highly resistant - rating of 1.0 Defects attributed to application, scoring, or mechanical damage -Moderately resistant - 1.0 < rating < 2.0 Minor or few defects - Resistant - 2.0 < rating < 3.0 Severe defects - Nonresistant - rating > 3.0

Coatings exposed for only 12 months at just two of the three field test sites are preceded with an asterisk.

- 1. Coatings for steel surfaces.
 - a. Highly resistant
 - (1) Urethane coating, proprietary (coating No. C-9)
 - (2) *Phenolic-epoxy, proprietary (coating No. C-12)
 - b. Moderately resistant
 - (1) Vinyl resin, USBR VR-6 (coating No. C-2)
 - (2) Coal-tar epoxy, MIL-P-23236, Type I, Class 2 (coating No. C-4)
 - (3) Phenolic, proprietary (coating No. C-8)
 - Resistant C
 - (1) Vinyl-resin, USBR VR-3 (coating No. C-1)
 - (2) *Urethane, proprietary (coating No. C-13)
 - (3) *Phenolic-epoxy, proprietary (coating No. C-16)
 - d. Nonresistant
 - (1) Coal-tar enamel, AWWA C203 (coating No. C-3)
 - (2) Butyl, proprietary (coating No. C-5)(3) Butyl, Proprietary (coating No. C-6)

 - (4) Coating for galvanized steel, proprietary (coating No. C-10)
 - (5) Galvanized, ASTM: A 123 (coating No. C-11)
 - (6) *Urethane, proprietary (coating No. C-14)
- 2. Coatings for concrete surfaces.
 - a. Highly resistant
 - (1) Coating No. C-9
 - (2) *Coating No. C-12
 - b. Moderately resistant
 - (1) None

- c. Resistant
 - (1) Urethane, proprietary (coating No. C-7)
 - (2) Coating No. C-4
 - (3) *Coating No. C-16
- d. Nonresistant
 - (1) Coating No. C-1
 - (2) Coating No. C-3
 - (3) Coating No. C-5
 - (4) Coating No. C-6
 - (5) *Coating No. C-13
 - (6) *Coating No. C-14
 - (7) *Urethane, proprietary (coating No. C-15)

Joint Sealers

The results of sealers for concrete joints are shown in tables 35, 36, and 37. Figure 31 shows typical defect-free and defective sealers. The evaluation summary for sealants appears in table 38.

The sealers are rated as follows according to their performance in all three exposure zones at the field sites.

Sealers exposed for 12 months only and at just two of the three field test sites are preceded with an asterisk.

No defects - Excellent - rating of 1.0 Surface defects only - Satisfactory - 1.0 \leq rating \leq 2.0 Adhesive or cohesive failure - Unsatisfactory - rating \geq 2.0

- 1. Excellent.
 - a. *One-component, low modulus silicone (code No. S-4)
- 2. Satisfactory.
 - a. Two-component polysulfide (code No. S-3)
- 3. Unsatisfactory.
 - a. Two-component silicone (code No. S-1)
 - b. Two-component urethane (code No. S-2)
 - c. *Two-component, slow-set polysulfide (code No. S-5)

TABLE 35. TEST RESULTS - SEALERS FOR CONCRETE JOINTS - SITE 1*
Sealant Defects***
Site Exposure

	Nominal	Gas	S	Inter	Interface	Liquoz	五01
Code No.**	exposure time, mo	25 percent extension	25 percent compression	25 percent extension	25 percent compression	25 percent extension	25 percent compression
S-1	3	No defects No defects	No defects No defects	No defects No defects	No defects No defects	No defects No defects	No defects
	22	No defects					
S-2	3	No defects	No defects	No defects	No defects	No defects	No defects
	10	No defects	No defects	75 percent bond	No defects	80 percent bond	No defects
	22	No defects	No defects	failure 75 percent	No defects	failure 100 percent	No defects
				failure		failure	
S-3	3	No defects	No defects	No defects	No defects	No defects	No defects
		cracking	cracking	Cracking	cracking	cracking	cracking
	77	cracking	Sullace cracking	Surrace cracking	surrace cracking	Surrace cracking	Surrace cracking

^{*} Site 1 - Tapia Water Reclamation Facility, Calabasas, Calfironia. ** See table 7 for sealer identification. *** See figure 31 for typical examples of sealant defects.

TABLE 36. - TEST RESULTS - SEALERS FOR CONCRETE JOINTS - SITE 2*
Sealant Defects***
Site Exposure

	Nominal	Gas		Inter	face	Liquor							
Code No.**	exposure time, mo	25 percent extension	25 percent compression	25 percent extension	25 percent compression	25 percent extension	25 percent compression						
S-1	3 10	No defects No defects	No defects No defects	No defects 100 percent bond fail- ure	No defects No defects	No defects No defects	No defects No defects						
	20	No defects	No defects	100 percent bond fail- ure	No defects	No defects	No defects						
	28	10 percent bond fail- ure	No defects	100 percent bond fail- ure	No defects	No defects	No defects						
\$-2	3	100 percent bond fail- ure	No defects	100 percent bond fail- ure	No defects	100 percent bond fail- ure	No defects						
	10	100 percent bond fail- ure	No defects	100 percent bond fail- ure	No defects	100 percent bond fail- ure	No defects						
	20	100 percent bond fail- ure	No defects	130 percent bond fail- ure	No defects	100 percent bond fail- ure	No defects						
	28	100 percent bond fail- ure	No defects	100 percent bond fail- ure	No defects	100 percent bond fail- ure	No defects						
\$-3	3 10	No defects Surface degrada- tion	No defects Surface degrada- tion	No defects Surface degrada- tion	No defects Surface degrada- tion	No defects Surface degrada- tion	No defects Surface degrada- tion						
	20	Surface degrada- tion	Surface degrada- tion	Surface degrada- tion	Surface degrada- tion	Surface degrada- tion	Surface degrada- tion						
	2 8	Surface degrada- tion	Surface degrada- tion	Surface degrada- tion	Surface degrada- tion	Surface degrada- tion	Surface degrada- tion						
5-4	3	No defects	No defects	No defects	No defects	No defects	No defects						
	12	No defects	No defects	No defects	No defects	No defects	No defects						
S-5	3 12	No defects Surface cracking	No defects Surface cracking	No defects 20 percent bond fail- ure	No defects Surface cracking	No defects 5 percent bond fail- ure	No defects Surface cracking						

 ^{*} Site 2 - Speedway Wastewater Treatment Plant, Indianapolis, Indiana.
 ** See table 7 for sealer identification.
 *** See figure 31 for typical sealant defects.

TABLE 37. - TEST RESULTS - SEALERS FOR CONCRETE JOINTS - SITE 3*
Sealant Defects***
Site Exposure

	Nomi nal	Gas		Inter	face	Liqu	or
Code	exposure	25 percent	25 percent	25 percent	25 percent	25 percent	25 percent
No.**	time, mo	extension	compression	extension	compression	extension	compression
S-1	3	100 percent bond fallure	No defects	100 percent bond failure	No defects	25 percent bond failure	No defects
	10	100 percent bond failure	No defects	100 percent bond failure	No defects	50 percent bond failure	No defects
	20	100 percent bond failure	No defects	100 percent bond failure	No defects	50 percent bond failure	No defects
	28	100 percent bond failure	No defects	100 percent bond failure	No defects	100 percent bond failure	No defects
S-2	3	100 percent bond fail- ure	No defects	100 percent bond fail- ure	No defects	100 percent cohesion failure	No defects
	10	100 percent bond fail- ure	No defects	100 percent bond fail- ure	No defects	100 percent cohesion failure	No defects
	20	100 percent bond fail- ure	No defects	100 percent bond fail- ure	No defects	100 percent cohesion failure	No defects
	28	100 percent bond fail- ure	No defects	100 percent bond fail- ure	No defects	100 percent cohesion failure	No defects
S-3	3	Surface degrada- tion	Surface degrada- tion	Surface degrada- tion	Surface degrada- tion	Surface degrada- tion	Surface degrada- tion
	10	Surface degrada- tion	Surface degrada- tion	Surface degrada- tion	Surface degrada- tion	Surface degrada- tion	Surface degrada- tion
	20	Surface degrada- tion	Surface degrada- tion	Surface degrada- tion	Surface degrada- tion	Surface degrada- tion	Surface degrada
	28	Surface degrada- tion	Surface degrada- tion	Surface degrada- tion	Surface degrada- tion	Surface degrada- tion	Surface degrada- tion
5-4	3	No défects	No defects	No defects	No defects		#
	12	No defects	No defects	No defects	No defects	No defects	No defects
S-5	3	No defects	No defects	No defects	No defects	#	*
	12	Surface cracking	Surface cracking	Surface cracking	Surface cracking	Surface cracking	Surface cracking

Site 3 - Westgate Wastewater Treatment Plant, Alexandria, Virginia
 See table 7 for sealer identification.
 See figure 31 for typical sealant defects.
 Sample could not be retrieved for this inspection.

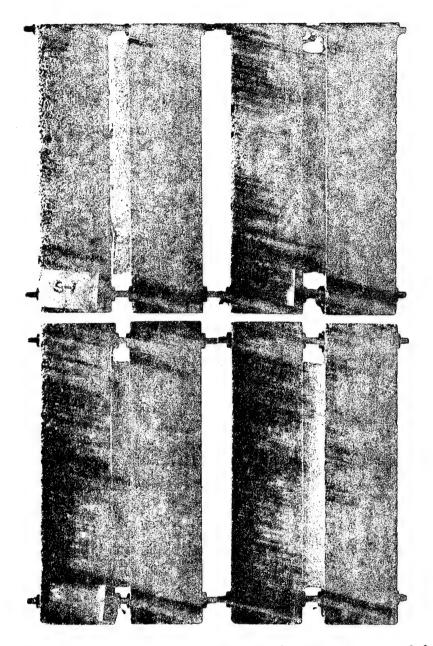


Figure 31. Typical joint sealer performance in these tests. S-l is a two-component silicone sealant which has incurred bond failure, S-2 and S-3 show surface degradation of two-component polysulfide base material exposed in compressed (S-2) and stretched (S-3) condition and S-4 is intact one-component, low-modulus silicone.

TABLE 38. EVALUATION SUMMARY - SEALERS FOR CONCRETE JOINTS Performance Rating 1/

		5/ Highest 6/	entre of the control					2.3							3.0						•	7.0						1.0						2.5
		Average	2 2	1.0	2.5	1.0	1.7	1.0		2.3	1.0	0 0	1.0	3.0	1.0		2.0	2.0	2.0	2.0	7.0	7.0	1.0	1.0	1.0	1.0	1.0	1.0		2.0	2.0	2.5	2.5	2.0
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Ctr. Car	exposure type			Interface Tension			Сошр			Татотбаса				Сощол			Interface Tone	citace lensi			Combi	Tension	Compr	Interface Tension			Compr	E	Tension	Interface Tension	Tallar and i			
opo			S-1. Gas	Int	-	Liquor			5-c Gas	101	7117	Lignor	777		5-3		Inte	9	Liquor			S-4 Gas		Inte	:	Liquor		S~5		Infe		Liquor		

1/ Assigned as follows: 1 - No defects
2 - Surface defects
3 - Adhesive or cohesive failure
3 - Adhesive or cohesive failure
3/ Speedway Wastewater Treatment Plant, Indianapolis, Indiana
4/ Westgate Wastewater Treatment Plant, Alexandria, Virginia
5/ Average of ratings assigned after final evaluation of sites exposed
6/ Highest (numerical value) of average ratings for given sealer

SECTION 7

DISCUSSION OF TEST RESULTS

Concrete

1. Length change. - One established method of determining progression of deterioration of concrete exposed to a given environment is to monitor its change in volume with respect to exposure time. Whereas loss in volume of concrete is normally merely indicative of dehydration, an increase in volume can show not only increase in saturation with water but also effects of chemical and physical reactions.

The expansive effects of both freeze-thaw deterioration and sulfate attack are examples wherein concrete deterioration can be manifested by an increase in volume. These increases in volume are the result of internal pressures produced by the freezing of water in freeze-thaw deterioration and by chemical reaction in sulfate attack.

Small volume changes of concrete are difficult to determine accurately. Therefore, its length, a dimension which is easily and accurately measured, is monitored as a reflection of its volume.

In addition to lengths, weights were also determined for control specimens exposed in 50 percent relative humidity at 23°C and immersed in Denver tap water at room temperature in the laboratories. Weight change of concrete when exposed to these two laboratory control environments is merely the result of absorption or loss of water.

Many materials expand with an increase in moisture content. This characteristic is shown for the concrete specimens exposed to the two laboratory environments by comparing weight change and length change results. Whereas only slight changes in both length and weight have occurred in those specimens exposed in air, substantial increases in both weight and length have resulted for all specimens immersed in water.

It is interesting to note that in all three sets of control specimens (those for site 1, site 2, and site 3) concrete made with Type II cement is the most absorptive. Permeability to water is an indication of concrete quality and density; higher permeability corresponds to lower concrete quality and density. Concrete made with Type V cement is slightly less absorptive. The polymer-impregnated concrete is substantially less absorptive than the other two, although not completely impermeable to water. In polymer-impregnated concrete, the voids present before impregnation are, to

some degree, filled with the polymer. Thus, there are fewer voids and, hence, less capacity for water to be absorbed.

The length change test results of samples exposed to site conditions are not so easily analyzed. The concrete specimens made from Type II and Type V cements increased in length initially in all three exposures (gas, liquid-gas interface, and liquor) at all three field sites. After this initial increase in length, which is undoubtedly the result of water absorption, the lengths of the specimens fluctuate, apparently due to the changing site conditions. Since no continuing tendency to increase in length is observed, it is concluded that field exposure has produced no detrimental effects to these two types of concrete. Additionally, the increases in lengths for these samples were well below the 0.2 percent generally accepted by the Bureau of Reclamation as indicative of impending concrete failure from sulfate attack. Complete failure in sulfate attack is considered to be 0.5 percent expansion. It is assumed that expansion caused by chemical or physical attack in an oxygenated wastewater environment can be judged by the same criteria.

It is evident that the PIC specimens in this study continue to increase in length with duration of exposure. In fact, although much less water is absorbed by the polymer-impregnated concrete than the other two concretes exposed in this study, its increase in length after 22 and 28 months of exposure is of the same magnitude as the other two concrete types. The expansion appears to be caused by moisture, as both wastewater and fresh water immersion result in continued increase in length of the same order of magnitude. There are at least two possible explanations for this continued length increase. First, since the voids in the polymer-impregnated concrete are plugged with the polymer, it simply may take longer for expansion to occur than it did in the conventional concretes. The expansion may then level off as it did for the conventional concretes. Because the specimens were ovendried prior to impregnation, the total expansion due to absorption may be greater than it was for conventional concrete. Secondly, moisture may have an adverse effect on polymer-impregnated concrete. If this were so, longer exposures should show continued expansion exceeding 0.2 percent. Further long-term exposure is needed to confirm or disprove this possibility.

2. Compressive strength. - The compressive strength cylinders were broken at a load rate of 14 000 kPa/min (2.0 x 10 1b/in min). At site 2, some of the compressive strength specimens came loose from the exposure rack and were irretrievable. It was therefore necessary to use the length change specimens, with metal inserts on each end to determine the 28-month compressive strength results. The ends were sawn off to remove the inserts and the shortened cylinders were tested. The results were corrected to equivalent results on cylinders with a length-to-diameter ratio of 2.6. As a check on the validity of this approach, the length change specimens were also tested for compressive strength at site 3 where the normal strength cylinders were also available. For concrete containing Type II and Type V cement, the strength results on the length change specimens were almost identical to the results on the compressive strength cylinders. This indicates that the 28-month values for site 2 are valid. The polymer-impregnated specimens at site 3 indicate variability in the 28-month strengths as determined by the two different sets of cylinders. This will be dis essed later.

In all compressive strength computations except the 28-month results at sites 2 and 3, the nominal diameter was used to compute the area. For the 28-month results, the length and diameter of all specimens were measured. This was because surface erosion had become significant at site 3 and because of the variation in length of the specimens with inserts that were sawed.

Concrete made with Type II cement shows no strength loss at any exposure site. For example, at site 1 all strengths exceed the strength at the time the specimens were first exposed. At sites 2 and 3, the initial strengths (strength at the time the specimens were first exposed) are slightly lower than the 28-day strengths but this is not significant and is probably due to variability in fabrication of the test specimens. At both sites 2 and 3, concrete containing Type II cement gained strength beyond the 28-day strength under all test conditions. At all three sites, each exposure condition (gas, interface, and liquor) produced higher strengths than the 50 percent relative humidity laboratory control specimen exposure. This indicates that sufficient moisture was present to continue hydration of the cement in all three exposure conditions and that the composition of the wastewater does not alter the normal cement hydration processes. In fact, results at sites 1 and 3 indicate that the cure at the field site was superior to the cure of laboratory specimens submerged in tap water.

In general, exposure of concrete containing Type II cement resulted in strength increase with age at all three sites. The small decrease shown in a few cases is not significant considering the variability of concrete and considering the fact that all strength values exceed the 28-day strength. The exposure of the concrete made with Type II cement to oxygenated wastewater treatment plant conditions did not reduce the compressive strength but provided continued moist curing which increased strength.

Results on concrete made with Type V cement for all three sites were similar to those for concrete made with Type II cement. For all three sites, all exposures produced compressive strengths greater than the initial strengths. In general, all exposure conditions produced stronger concrete than the laboratory 50 percent relative humidity cure, indicating hydration of the cement is being continued by the presence of moisture. Again, results from sites 1 and 3 indicate that curing at the site produced stronger concrete than laboratory cure with specimens submerged in tap water. As with the Type II cement concrete, the Type V cement concrete, in general, showed an increase in compressive strength when exposed to various oxygenated wastewater treatment plant environments.

The polymer-impregnated concrete specimens showed large variations in strength under most exposure conditions, although all strength values exceeded the highest strengths for conventional concrete. For sites 2 and 3, all exposures produced strengths lower than the initial strength. At all three sites there are exposures showing a decrease in strength with length of exposure. There are also exposures at all three sites that show no consistent trend.

Results at site 3 at 28 months of exposure are especially significant. Two sets of specimens were tested at this exposure time. The first set was

the specimens that had been fabricated for compressive strength testing. second set was composed of length change specimens with the ends sawn off to remove the metal inserts. Results were corrected to a length-to-diameter ratio of 2.0. As mentioned previously, results on concrete made with Type II and Type V cement indicate that both sets of specimens gave similar results. For the polymer-impregnated specimens, however, this was not the case. In both the interface and the liquor exposures, there is a significant difference in the strengths of the two sets of specimens at 28 months of exposure. Thus, there is variability in strength of the polymer-impregnated specimens even when exposed under identical conditions. Since some of the compressive strengths of the polymer-impregnated concrete are significantly lower than the initial strengths, we must conclude that one of two possibilities caused this strength difference. Either the polymer-impregnated specimens are losing strength at different rates (even if in the same environment) or the specimens were not uniform in strength initially after polymerization. From the test results alone, it is not possible to prove which of these two possibilities caused the strength variations.

3. Surface erosion. - Generally, only minor changes in surface conditions have occurred at the Tapia and Speedway sites.

At the Westgate site, the most severe erosion occurred in the interface zone in the concrete fabricated with Type V cement. Less severe erosion was observed in all zones with the Type II specimens although noticeable change can be seen in the Type II vapor specimens. Good compressive strength and lack of significant volume change indicate that this is a surface condition. The polymer-impregnated concrete was only slightly altered in appearance. Results at 28 months of exposure were similar to those at 10 months with the erosion of the Type V and Type II cement concretes continuing.

As mentioned earlier, debris not trapped by the bar screen at the Westgate site were fed into the secondary treatment tank where the test specimens were exposed. These solids are removed in primary treatment at the other two sites. It is concluded that these solids inflicted the abrasion damage to the concrete cylinders. The fact that specimens in vapor exposure were also affected is explained by the turbulence of the liquor and water within the tark.

Steel Embedded in Concrete

Portland cement-mortar and -concrete coatings on steel derive their corrosion-inhibiting quality from formation of an insoluble, passivating, oxide film on the steel surface due to the highly alkaline environment. In addition, when voltage is imposed on a mortar- or concrete-coated steel surface, this film generates a counter-voltage (polarization) such that, within limits no current will flow. This passivity and resistance to current flow developed by properly designed, dense, high-quality portland cement coating are sufficient to overcome the potential differences in virtually all naturally occurring fresh water and soil conditions. Environments high in concentration of chloride ions are the major exception. Therefore, the excellent performance of concrete in preventing corrosion of embedded steel in these tests was not surprising. The highest concentration

of chloride observed was at site 1. At site 1 the chloride concentration was found to be 144 mg/ℓ . Seven hundred mg/ℓ chloride is the generally accepted threshold concentration above which passivity may be destroyed provided the chloride is accompanied by oxygen.

Alloys

1. Unstressed specimens. - The poor performance of aluminum, gray cast iron, and carbon steels in this test was anticipated.

Aluminum alloys are notorious for their susceptibility to pitting in high solids waters such as wastewater. Aluminum alloys derive their corrosion resistance from formation of a passive oxide film on their surfaces. Nearly all corrosion of aluminum results from deterioration of this passive film in localized areas resulting in pitting. Since aluminum has been found to pit deeply in conventional plants, it appears that the poor performance in these tests cannot be directly attributed to oxygenation.

Carbon steels have been found to pit in aerated, near-neutral waters. Corrosion in aqueous environments is basically an electrochemical reaction wherein electrons are released at the anode with metallic ions formed by oxidation going into solution. At the cathode, electrons are accepted and negative ions form. Action at the anode and cathode are interdependent, i.e., neither can proceed without the other. In the case of iron (steel) in water, iron goes into solution as ions and electrons are left behind in the metal at the anodic areas. These electrons travel through the steel to the cathode where they combine with hydrogen ions to form hydrogen gas. In neutral, slow-moving waters, the evolution of hydrogen gas at the cathode proceeds and accumulates as a layer of hydrogen on the metal. This layer decreases the cathodic reaction and thus the reaction is referred to as cathodic polarization. Therefore, corrosion proceeds very slowly in quiescent, deaerated waters. Dissolved oxygen in the water upsets the equilibrium condition established by cathodic polarization. The oxygen reacts with the accumulated hydrogen to form water. As the hydrogen is removed in this manner, corrosion is allowed to proceed. Dissolved oxygen concentration, therefore, controls the rate of corrosion of iron and steel in wastewater.

Corrosion of gray cast iron was by a process of selective dealloying commonly referred to as graphitization or graphitic corrosion. Cast iron consists mainly of iron and carbon with small amounts of silicon and manganese. The graphite is cathodic to iron, and thus an excellent cell exists. The iron is selectively dissolved leaving a porous mass of graphite, voids, and corrosion products.

Both copper and the austenitic cast iron suffered moderate uniform corrosion rates, less than 250 $\mu\text{m/yr}$ (10 mil/yr). Sensitized 304 and 316 austenitic stainless steels were rated as only moderately resistant because of some minor pitting observed in the gas zone at one of the test sites. This pitting corroborates our past experiences as well as those of other investigators, in which sensitized austenitic stainless steels have been found to be susceptible to pitting. Sensitization is caused by heat treatment such as welding followed by slow cooling. The generally accepted theory

for this phenomenon is that this treatment results in chromium carbide precipitation at the grain boundaries which in turn reacts galvanically with adjacent metal devoid of chromium. This phenomenon is known as intergranular cortosion.

As anticipated, the stainless steels, Types 201, 304, and 316, provided excellent resistance to these environments.

2. Stressed specimens. - Of the alloys exposed in the stressed condition, all passed this "go-no go" type of test except mild steel, low alloy steel, and aluminum. Since these materials also were found to be nonresistant when exposed as unstressed coupons, it is difficult to assess the effect of the stress. However, it was noted that all splitting occurred at the highly stressed, plastically deformed ends of the test specimens. Therefore, it appears that stress on these alloys in these environments does accelerate the rates of deterioration of these nonresistant materials.

Rubber and Plastics

Relatively little detrimental change has occurred in the rubber and plastic materials. Such changes that did occur were the result of specific environmental conditions which reacted somewhat differently, both in type and extent of reaction, with each polymer group. In addition to the different reaction of each basic polymer, behavior of specific products is greatly influenced by the variety of substances which are added to the compound, such as antioxidants, antiozonants, curing accelerators, cross linking agents, fungicides, reinforcing fillers, antibacterial agents, and extenders. For example, a material which might be a good antibacterial agent could adversely affect the oxidation rate of a polymer, or two manufacturers' products using the same polymer may perform differently as a result of the type or amounts of such additives.

The factors in the environment of this study which could be expected to influence the behavior of polymers are:

- Oxidation (including ozone attack)
- 2. Biological attack
- 3. Water
- 4. Physical damage

Thermal degradation and photodegradation will not be considered to any extent because of the relatively cool operating temperatures and the absence of sunlight at the exposure sites.

l. Oxidation. - Since this study deals with oxygenated systems, it is important to know that oxygen is generally the most common factor in polymer degradation. All polymers react with oxygen at combustion temperatures and sunlight generally accelerates the process. Fortunately, with the absence of light and with the low temperatures encountered in this study (14° to 26°C), oxidation proceeds very slowly for most polymers. For example, the oxidation rate of linear polyethylene at 140°C is roughly 10 times the rate at 100°C. Furthermore, at 100°C,

oxygen uptake reaches a relatively early plateau. Measurement would be difficult at temperatures below 30°C since the rate of oxygen absorption is extremely slow. Even natural rubber absorbs oxygen very slowly at temperatures below 50°C.

Polymer selection is basic in reducing oxygen attack potential. Oxidation in polymers is a complicated process that involves chain reactions which result in the formation of unstable peroxy free radicals. Olefinic unsaturated hydrocarbon double bonds and other unsaturated functional groups present favorable sites for stabilization of these free radicals. Thus, silicone polymers (R-32 and -532) with their silica-oxygen molecular backbone are among the most stable toward oxidative degradation. Ethylene propylene diene monomer (R-8 and -30), which has residual unsaturation only in pendent side groups and not in the main chain, is very stable as is unbranched polyethylene. Branching generally decreases oxidation resistance. Butyl rubber (R-17 and -29), having its hydrocarbon chain interrupted by a relatively few double bonds, is also quite resistant to attack. Natural rubber (R-25) with its high chemical unsaturation (presence of double bonds) is among the most susceptible of polymers to oxidation. Nevertheless, natural rubber was included in this study since it is still widely used, especially in items such as water pipe gaskets.

Modification of polymer chains by addition of electrophilic side groups such as chlorine in neophrene rubber (R-5) has a protective influence on the double bond. This is generally more permanent protection than is reliance upon antioxidants, which are used up in the performance of their function. Where oxidation rates are very low, antioxidants may provide satisfactory protection.

The effect of ozone on polymers is similar to normal oxidation in that it attacks the double bond but the process is simpler since the attack is direct. An energetic reaction occurs as a result of the electrophilic character of ozone. Scission of the double bond occurs in a reaction between the electron-deficient terminal oxygen atom of the ozone molecule and the electrons of the double bond, ultimately resulting in the formation of polyperoxide and carbonyl compounds.

Unlike oxidation, in ozonation the thin film of the ozone reaction product (approximately 10 mm) is sufficient to restrict the access of ozone molecules to the underlying rubber if the rubber is unstrained. Therefore, unless rubber is strained (usually beyond 3 to 5 percent elongation), it appears not to have been affected by ozone and indeed suffers no significant damage. In the strained state, cracks appear which generally vary inversely in depth and directly in number to the degree of strain, with little change in the rubber between cracks.

As would be suspected the resistance of different rubber products to ozone attack is similar to their resistance to oxidation.

No unusual behavior of rubber or plastic products with regard to oxidation has been experienced in this study. The only attack of oxygen

(0₂ or 0₃) that is significant is ozone cracking in the natural rubber (R-25) and in the nitrile-butadiene rubber (R-34). These two materials were highly sensitive to ozone. In tests conducted at the Bureau of Reclamation Laboratories, both materials developed cracking within 8 hours when exposed to an atmosphere of 0.5 ul/l ozone at 38°C. Initial ozone cracking could also be observed after 12 days in the laboratory atmosphere of less than 0.05 ul/l ozone and approximately 25°C.

It is significant that no difference in cracking was observed in any of the three zones nor was there any increase in cracking between the 3- and 9-month inspections. There was a difference in severity between sites corresponding to least delay (Tapia) and greatest delay (Westgate) in the time between stressing the specimens and installation at the sites. (It was necessary to stress the specimens prior to shipment.) Specimens of natural rubber stressed at the same time as the Westgate specimens and immersed in tap water at the Bureau of Reclamation Laboratories at the same time that the Westgate specimens were installed show nearly identical severity of ozone cracking at a 9-month inspection as the Westgate specimens, whereas specimens immersed immediately after stressing showed no evidence of cracking. Therefore, it is concluded that the cracking occurred before samples were installed at the test sites and not as a result of the oxygenated wastewater environment.

This environment does not represent a very severe oxidation environment insofar as higher polymers are concerned. This is evidenced by the lack of substantial difference in physical properties between the tap water and the wastewater specimens, as well as between specimens exposed in gas and liquor zones. It is also indicated by the relative stability after the 3-month exposure in the undamaged natural rubber and the nitrile-butadiene rubber which, among polymers selected for this study, are known to be the most sensitive to oxidation.

2. Biological attack. - Certain types of bacteria can utilize hydrocarbons, including rubber, as energy sources in their metabolism. Widespread deterioration of natural rubber water pipe joint gaskets in Europe has been reported to be the result of attack by two types of bacteria of the genus streptomyces. No deterioration of synthetic rubbers (other than polyisoprene) has been reported in Europe and no deterioration of natural rubber, widely used for pipe gaskets in the United States, has been reported. Accelerated soil micro-organism tests conducted by the Bureau of Reclamation on several rubber products (mainly butyl and ethylene propylene diene monomer) have shown no adverse effect after 10 years of exposure. It appears that rubber compounds most resistant to oxidation and ozone attack may possibly be the most resistant to attack by mico-organisms. Indeed, P. B. Dickenson, in the Rubber Journal (August 1965), opines that biological degradation of rubber must be preceded by an oxidation process that breaks the long hydrocarbon chain into shorter molecules which may then be consumed. In contradiction to this, some evidence of bacteria attack on the highly oxidation-resistant silicone rubbers has been reported and butyl rubber

may be affected by sulfate-reducing bacteria. The polyethylene family of polymers, including chlorinated (B-6475) and chlorosulfonated polyethylene (R-18), appears to be highly resistant to micro-organism attack, as is the polyvinyl chloride (PVC) resin, although plasticizers used in flexible PVC (B-6414) are commonly attacked with resultant stiffening of the material.

Results of these tests indicate some samples have suffered biological attack. One natural rubber (R-25) sample after 9 months of exposure in the mixed liquor at the Tapia site showed some sign of localized attack. Several small circles (3 to 6 mm in diameter) showed discoloration and pitting accompanied by deterioration to a depth of approximately 1 mm. Discoloration in one silicone rubber may also have resulted from micro-organism attack. The flexible PVC has shown some stiffening as well as some increase in yield strength indicating attack on the plasticizer. However, the increase in strength indicates no resin attack. During more than 10 years of USBR field experience with flexible PVC in canal lining, the relatively slow loss of plasticizer has caused no problems where protection from mechanical damage has been maintained. The plasticizer loss eventually produces a rigid PVC sheet. Rigid PVC has been used as a liner, but it is difficult to handle during installation, does not conform well to uneven subgrades, and in general is more labor-intensive than flexible PVC sheets.

3. Water attack. - Reaction of water with polymers merits serious study especially where continuous immersion is involved. In this study water reaction may have less potential for deterioration than microorganism attack. The reason for this is the high availability of micro-organisms in the wastewater and because only materials known to be resistant to water attack were selected for exposure. However, for certain materials, water attack may be of primary significance. Although some studies have shown that in aerated water, immersion oxidation rates are reduced, other properties may be affected.

As in the case with oxidation, reaction of polymers with water may lead to chain scission (softening and decompositon) or to cross linking (hardening and brittleness). Previous USBR experience has shown embrittlement occurring in the polyacrylate (R-27) from water attack although at somewhat higher temperature than occurs in wastewater treatment plants. The polyacrylate, therefore, was closely observed for indications of water attack. Attack of water on polymers must be preceded by permeation of the water through the bulk of the polymer. This is usually accompanied by some evidence such as unusual softening or swelling which has not been observed in the polyacrylate. Further the changes in the physical properties of the polyacrylate although somewhat erratic appear to have stabilized.

4. Physical damage. - A wide variety of physical abuse has been encountered by samples exposed to the three sites in this study and at least as wide a range can be expected elsewhere. The principal damage

sustained has been tensile rupture of both silicone (R-32 and -532) specimens and a deep scratch in one reinforced chlorinated polyethylene (B-6468) and one reinforced butyl (B-6464), all at the interface of the Westgate plant.

5. Other damage. - Some unusual swelling of butyl and EPDM rubber samples occurred at the interface location at site 2. An oil spill was suspected by plant operators during the period in which swelling was encountered. In localities where problems of continuous contact with liquid hydrocarbons occur, the long-term effect of such exposure should be investigated.

Protective Coatings

To facilitate evaluation of the large number of coatings specimens exposed in this study, a numerical rating system was established to reflect performance. Performance of coatings after each exposure interval at each exposure zone at the three test sites was designated numerically as follows:

- 1. No defects.
- 2. Defects attributable to scoring of the protective coating film, such as blistering around the score only, or mechanically induced, such as by impact or abrasion.
- 3. Few or minor defects. A minor defect was defined as one which did not impair the protective effectiveness of the coating. Examples include blistering of the topcoat only and few, small blisters.
- 4. Severe defects. Severe defects include cracking and gross blistering.

Such a numerical rating system allows almost unlimited flexibility for mathematical manipulation and makes analysis of a large number of specimens exposed for various periods of time in three zones of three test sites manageable.

The performance of standard USBR immersion coatings, VR-3, VR-6, coaltar enamel, and coal-tar epoxy, in these exposures was disappointing. Whereas these materials normally provide a minimum of 20 years of service, with minimal maintenance, when exposed to fresh water, defects appeared after only short exposure periods in these wastewater environments.

The VR-3 and, to a lesser degree, the VR-6 vinyl systems proved to be susceptible to blistering, the coal-tar enamel to pattern cracking, and the coal-tar epoxy to slight alligator cracking.

It is interesting to note, however, that of the coatings obtainable under standard specifications exposed, the coal-tar epoxy and the VR-6 proved to be most resistant.

The cracking of the coal-tar enamel coating which resulted in an overall evaluation in the nonresistant category is difficult to explain. This coating is projected to have a 50- to 100-year service life in Bureau applications. It is surmised that the highly oxidative nature of oxygenated wastewater resulted in scission of the coal-tar polymer chains. Heretofore, cracking of this enamel has been experienced only when exposed to cold temperature and to sunlight exposure.

Both coatings which received highly resistant ratings for steel also received highly resistant ratings when tested over concrete. These were the phenolic-epoxy and urethane coatings, both proprietary materials. At that point, similarity of performance over the two substrates ceased to exist. Whereas 8 of the 14 coatings applied to steel were rated resistant or higher, only 5 of the 10 coatings tested on concrete substrate achieved this rating. In addition, whereas three materials received a moderately resistant rating when applied to steel, none of the coatings tested on concrete achieved this rating. These comparisons indicate that concrete surfaces are more difficult to protect by coating.

Joint Sealers

Of the five joint sealers exposed, only one, the single component, low-modulus silicone sealant survived the test free of defect. Commonly used sealers for such applications, including the urethane and silicone, both two-component materials conforming to Federal Specifications TT-S-00227, failed to maintain bond to the concrete in these tests, whereas the two-component polysulfide material, also conforming to TT-S-00227, displayed surface distress but no adhesion or cohesion failure.

The continuous stress imposed on the sealants during these tests, i.e., 25 percent tensile and 25 percent compressive, is quite severe. Nevertheless, recognizing that Federal Specification TT-S-00227 requires materials resistant to a total joint movement of 50 percent and since the same stresses were applied to all sealants, the test should not be considered unfair.

These test results should not be used out of context, i.e., the stress imposed during these tests should be compared to stresses to be expected by the design of specific joints. However, since the single-component, low-modulus silicone material performed without defect when stressed to 25 percent extension and compression, one can safely assume that this sealer would perform well at lower stress levels also. Also, if such lower stress levels are anticipated, although the polysulfide material rated higher than either the two-component silicone or the urethane sealers, the selection of the latter materials is indicated because the silicone and urethane materials themselves were not attacked as were the polysulfide sealants.

SECTION 8

DISCUSSION OF ECONOMIC IMPACT

Some of the materials recommended for an oxygen activated-sludge plant, as indicated by the results of these tests, are more expensive than those ordinarily used in conventional activated-sludge plants. The costs of necessary materials substitutions and additional requirements were considered in order to evaluate the economic impact of the materials recommendations.

This study was limited to comparison of relative costs of materials exposed in those plant locations where elevated oxygen concentrations occur as a result of oxygen injection: in the aeration basins (mixed liquor tanks) and in piping, valves, etc., between aeration basin outlets and secondary clarifier inlets. Components in these locations include the concrete tanks and covers (if any) of the aeration basins and various flow channels; slide gates and sluice gates; waterstops and joint sealers; piping and valves; metal railings, probes, hardware, etc.; plus protective coatings as required for these surfaces. The corrosion potential in other plant locations would be essentially the same as in a conventional plant. Since special equipment for mixing and for generating and handling oxygen are not required in a conventional plant, costs for these items were not evaluated. Other cost differentials, such as for operating costs and capital costs due to the differences in processes (for example, aeration basin size) are not within the scope of this study.

The wide range of wastewater treatment plant designs made it impossible to determine a single set of traditionally used materials for either conventional or oxygen treatment plants. Obtaining general materials cost data applicable to either type of plant was also not feasible. However, by considering, in detail, the designs and materials specifications of two typical oxygen plants and the costs of using alternative materials, it was possible to obtain sufficient information to draw an overall conclusion in regard to economic impact; namely, that the additional costs of corrosion-resistant materials recommended for an oxygen plant are negligible as compared to total construction costs.

Chosen for economic evaluation were the Englewood-Littleton, Colorado plant and the new expansion of the Denver Metropolitan Sewage District plant, both currently under construction. The 880-L/s (20-Mga1/d) Englewood-Littleton plant uses Food Machinery Corporation's (FMC) MAROX system and was designed by Henningson, Durham, and Richardson (HDR). The 3200-L/s (73-Mga1/d) Denver Metro plant addition contains Union Carbide's UNOX system and was designed by CH2M-Hill.

These sewage districts and engineering design firms were contacted to obtain specific details concerning relevant components and materials of construction. Upon studying the designs, specifications, and some cost data for the two plants, it became apparent that the present materials recommendations would have the greatest economic impact on the costs of sluice or slide gates. However, it also developed that the installed costs of these gates and their differential costs among alternative materials were clearly insignificant as compared to the overall construction costs, which are dominated by costs of concrete structures. These two case studies are detailed below.

Case I: Englewood-Littleton Plant

In the Englewood-Littleton plant, all specified materials, with one exception, are in agreement with the present materials recommendations. This exception is that the slide gates are constructed of aluminum rather than of a more corrosion-resistant material. According to the project engineer for HDR, aluminum was chosen because it traditionally has been used for slide gates in conventional plants. HDR considered that specifying a more corrosion-resistant material was not necessary, although they were not aware of any corrosion data or operating experience with the MAROX system to substantiate their selection of aluminum. They based their choice upon past performance in conventional plants.

The costs of the aeration basin slide gates for the Englewood-Littleton-plant were obtained from the local respresentative of ARMCO Steel Corporation, the manufacturer of these gates. ARMCO also supplied cost data for gates constructed of the recommended materials. A cost of coating with coal-tar epoxy $[\$30/\text{m}^2\ (\$3/\text{ft}^2)$ of surface installed, which may be conservatively high] was used to calculate costs for epoxy-coated carbon steel slide gates.

Results (table 39) indicate that the additional cost of using stainless steel as compared to aluminum is only \$12,600 for all 78 gates and is clearly insignificant in comparison to the total plant cost of just over \$20,000,000. These results also indicate that a savings would have been realized by using coal-tar epoxy coated mild steel slide gates as compared to the unprotected aluminum. However, the corrosion and abrasion resistance of material for construction of components exposed to severe abrasion and wear, e.g., gate seals and seal contact surfaces, should be considered since on these areas, protective coatings can be quickly worn away.

The above slide gates are for low-pressure applications. Higher heads [greater than 15 kPa (5 feet of water)] would require different designs of sluice gates and different materials such as cast iron. For example, the cost of an ARMCO 0.61- by 0.61-m (24- by 24-inch) cast iron sluice gate is \$1,750, and of a similar 1.5- by 0.76-m (60- by 30-inch) gate, \$4,900. Adding an epoxy-coal-tar coating would increase each of these prices by less than \$200. Again wear surfaces would require special consideration.

TABLE 39. COMPARISON OF COST* OF SLIDE GATES**

		CO	Cost		
Material of construction/ protective coating	0.6 m x 0.6 m l gate	0.6 m x 0.6 m (24 in x 24 in) 1.5 m x 0.7 m (60 in x 30 in) 1 gate 1 gate 48 gates	1.5 m x 0.7 m l gate	(60 in x 30 in) 48 gates	Total cost 78 gates
Carbon steel/coal- tar paint ***	\$350	\$10,500	\$525	\$25,200	\$35,700
Carbon steel/galvanize***	370	11,100	625	30,000	41,100
Carbon steel/epoxy***	374	11,220	563	27,000	38,220
Aluminum/none	800	24,000	1,250	000,09	84,000
Stainless steel/none	006	27,000	1,450	009,69	96,.600

Provided by Armco Steel Corporation. Comparisons between tables should not be made because of differences in accessories and gate applications.

Required for aeration basins at Englewood-Littleton Sewage Treatment Plant. *** **

Wear surfaces should be constructed Coating of all surfaces of these gates is not applicable, of corrosion and abrasion resistant materials.

Case II: Denver Metro Plant

In the Denver Metro plant addition, all materials in the covered aeration basins and piping to the secondary clarifiers are in agreement with present materials recommendations. Sluice gates are coal-tar epoxy coated cast iron. Waterstops and joint sealers consist of such recommended materials as neoprene rubber and polysulfide sealant, respectively. Concrete is the predominant material used in the aeration basins and represents the largest cost.

The costs of the cast iron sluice gates (complete installation including stems, hoists, anchor bolts, etc.) as supplied by their manufacturer, Rodney Hunt Company, are given in table 40. Also listed are prices which include the additional costs of epoxy coal-tar coating, assuming 30/m (3/ft) for coating materials and labor. Note that the relative cost of adding this coating is less than 1 percent of each gate price, but some surfaces of the gate may not be suitable for coating, e.g., high wear areas.

Prices for various sizes of fabricated slide gates of aluminum and stainless steel (table 41) were also obtained from the Rodney Hunt Company. Although these slide gates have the same opening as the sluice gates in table 40, they would probably not be serviceable at the Denver Metro plant because of the higher heads and other requirements. Note that these cost data agree with those in table 39; aluminum slide gates prices are less than 20 percent cheaper than those of stainless steel in these sizes.

A rough estimate of the installed costs of waterstops and joint sealers in the Denver Metro aeration basins was \$12,000. Variations in this value among various materials alternatives were found to be insignificant (installation is the largest portion of total waterstop or joint sealer cost) as compared to total capital cost. Total cost of the Denver Metro plant addition is about \$25,000,000.

COMPARISON OF COSTS OF COATED AND UNCOATED CAST IRON SLUICE GATES* TABLE 40.

		Unit cost	cost	Number	Total cost	cost
)	Gate size	Uncoated**	Coated***	used	Uncoated	Coated
48 ir	48 inches by 48 inches	\$5,176	\$5,272	&	\$ 41,408	\$ 42,176
30 ir	30 inches by 48 inches#	8,608	8,668	œ	68,864	69,344
60 in	60 inches by 72 inches	8,545	8,725	1	8,545	8,725
42 in	42 inches diameter	5,536	5,594	10	55,360	55,940
	TOTAL			27	\$174,177	\$176,185

Used in the aeration basins of the Denver Metropolitan Sewage Treatment Plant.

Provided by the Rodney Hunt Company. Prices for complete installation including stems, hoists, anchor bolts, etc. Comparisons between tables should not be made because of differences in accessories and gate applications.

Estimated assuming an added cost of \$3 per square foot for a coal-tar epoxy coating. However, coating of all surfaces of these gates is not applicable. Wear surfaces should be constructed of corrosion and abrasion resistant materials. ***

Includes costs of a special electric operator.

TABLE 41. COMPARISON OF COSTS* OF SLIDE GATES CONSTRUCTED OF STAINLESS STEEL AND ALUMINUM

	Cost	
Gate size	Stainless steel	Aluminum
1.2 m by 1.2 m (48 in by 48 in)	\$4,444	\$3,508
0.7 m by 1.2 m (30 in by 48 in)**	7,779	7,059
5 m by 1.2 m (60 in by 48 in)	7,079	5,648
1.0 m diameter (42 in diameter)	4,778	4,018

^{*} Provided by the Rodney Hunt Company. Comparisons between tables should not be made because of differences in accessories and gate applications.

** Includes cost of a special electric operator.

APPENDIX

Typical Concrete Mix Data

	Type II and polymer-impregnated	Type V
Cement, Laboratory No. Aggregate source Cement content, cement/concrete Sand content, percent by volume of aggregate Water-cement ratio	M-6400 Clear Creek <u>1/</u> 977 kg/m ³ (549 lb/yd ³)	M-5207 Clear Creek <u>1/</u> 934 kg/m ³ (525 lb/yd ³)
by weight Slump Entrained air, percent Total aggregate,	0.51 76.2 mm (3.0 in.) 5.6	0.51 83.8 mm (3.3 in.) 6.0
aggregate/concrete	5319 kg/m ³ (2990 lb/yd ³)	$5367 \text{ kg/m}^3 (3017 \text{ lb/yd}^3)$

^{1/} A local aggregate deposit used in Bureau of Reclamation concrete testing programs.

Aggregate Gradation

	Sand			
No. sieve <u>2</u> /	Opening (mm)	Percent retained	Coarse aggregate Size	Percent
Pan	_	5	/ 76-0 52 // 2/2 : >	
100	0.149	16	4.76-9.53 mm (4-3/8 in.)	40
50	0.297	24	9.53-19.05 mm (3/8-3/4 in.)	
30	0.59	25	7.75-19.05 mm (3/8-3/4 in.) 60
16	1.19	15		
8	2.38	15		
Total				-
TOTAL		100		100

^{2/} U.S. Standard sieves.

Type II and Type V portland cement concrete specimens were cured for 14 days at 23°K (73.4°F) and 100 percent relative humidity. The specimens were then stored at 23°K (73.4°F) and 50 percent relative humidity until shipped to the test site for exposure.

Concrete-impregnation Procedure

Specimens prepared for impregnation were treated as follows:

- 1. Cure 10 days at 100 percent RH, 23°K (73.4°F).
- 2. Dried in oven at 163°K (325°F) for 24 to 72 hours.
- 3. Cooled to room temperature for 24 hours.
- 4. Weighed to nearest 0.1 gram.
- 5. Specimens impregnated:
 - a. Vacuum of 100 kPa (1 atmosphere) applied to impregnator for period 1/2 hour
 - b. Impregnant, methyl methacrylate (MMA) monomer catalyzed with α , θ , butylazo isobutryonitrile, stirred for 1/2 hour
 - c. Impregnant introduced into impregnator while vacuum was being maintained
 - d. Vacuum released from impregnator and 376 kPa (40 lb/in²g) pressure applied using compressed air
 - e. Pressure soaked in catalyzed monomer for 1 to 1-1/2 hours
 - f. Pressure reduced to 100 kPa (atmospheric)
- 6. Polymerization of catalyzed monomer-impregnated specimens was accomplished by wrapping in foil and heating in oven to 75°C (167°F) for a period of 16 hours and allowed to cool to room temperature.
 - 7. Specimens weighted to nearest 0.1 gram.

Percent loading was calculated for each specimen from the impregnated and dry weights. Average loading was 6.47 percent by weight.

Metals and Alloys

Corrosion coupons for the stressed and unstressed corrosion tests were procured from Corrosion Test Supplies Company, Baker, Louisiana. Data contained on certificates submitted are shown in table 1.

The circular unstressed and rectangular stressed corrosion specimens were prepared for exposure as follows:

- Degreased in hot vapor degreaser using perchloroethylene solvent
- 2. Washed with grit soap until free of water breaks

- Sensitized specimens (304 and 316 SS only) were then heated to 650°C (1200°F) for 1 hour and cooled slowly
- 4. Circular coupons weighed to nearest 0.1 milligram
- 5. Mount circular coupons on corrosion test spools
- Stress rectangular specimens [bend over 25.4-mm (1-inch mandrel)]

Cleaning procedure following exposure was accomplished as follows:

- 1. Photograph
- 2. Wash carefully to remove all soluble material with soap
- 3. Chemical cleaning of respective specimens as shown below:

Stainless steels: Washing with soap using a stiff-bristle brush and rubber stopper

Cast iron, mild steel, low alloy steel, and austenitic cast iron: Immersion in hot caustic solution (20 percent sodium hydroxide with 200 grams of zinc dust added per liter), followed by washing with soap using a stiff-bristle brush and rubber stopper

Copper: Immersion in 70 percent nitric acid solution followed by washing with soap using stiff-bristle brush and rubber stopper

4. Drying and weighing to nearest 0.1 milligram

Corrosion rate was calculated using the following formula:

Corrosion rate =
$$\frac{(WL) \times (534)}{(D) \times (A) \times (T)}$$

where: Corrosion rate is in mils/year

D is the metal density in grams/cubic centimeter
A is the surface area of the coupon in square inches
T is the exposure time in hours, and

WL is the weight loss in milligrams

or: Corrosion rate = $\frac{WL}{DAT}$

where: Corrosion rate is in millimeters/year 3
D is the metal density in milligrams/mm 2

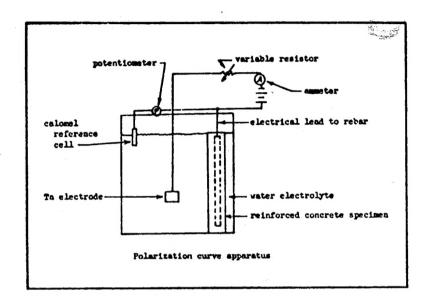
A is the surface area of the coupon in mm

T is the exposure time in years
WL is the weight loss in milligrams

Steel Reinforcement in Concrete

Polarization Break Method of Determining Corrosion Rates of Steel Reinforcement Embedded in Concrete

Sketch of test schemtic is shown below.



Current is slowly increased by decreasing the resistance (variable resistor) until the impressed current is sufficient to overcome the anodic corrosion current. This point is determined by plotting the steel to electrolyte potential versus the log of the impressed current (E log I curve). The anodic current is the current at the break in the E log I curve. Similarly the cathodic corrosion current is determined by reversing the polarity of the cell. The corrosion current is then computed from the formula below:

$$I = \frac{Ia \ Ic}{Ia + Ic}$$

where: I is the corrosion current (amperes)

Ia is the anodic current (amperes)

Ic is the cathodic current (amperes)

The corrosion rate is then computed as follows:

$$W = F \times I \times t$$

where: W is the weight loss due to corrosion

F is Faraday's Number, 9.07 kg/ampere/yr (20 lb/ampere/yr) for steel

t is time (years)